CONCEPT MAP

FIVE KINGDOM CLASSIFICATION

The scientific procedure of arranging organisms into groups and subgroups on the basis of their similarities and dissimilarities and placing them in a hierarchy of categories is called **biological classification.** The earliest classification systems recognised only two kingdoms of living things: Animalia and Plantae followed by three and four kingdom classifications introducing Kingdom Monera and Protista. The most accepted and latest five-kingdom classification was proposed by **R.H. Whittaker** in 1969 to develop phylogenetic relationships. In this classification, the organisms are classified on the basis of following criteria : (i) complexity of cell, (ii) complexity of the body organisation, (iii) mode of nutrition, (iv) mode of reproduction, (v) ecological role and (vi) phylogenetic relationships.

Classification Criteria

Major Ecological Role — **Producer** → **Decomposer** → **Consumer**

Mode of Nutrition — **Autotrophy** (Photosynthesis) → **Heterotrophy** (Absorption) → **Heterotrophy** (Ingestion)

Complexity of Organism — **Multicellular** / **Unicellular**

Complexity of Cell — **Eukaryotes** / **Prokaryotes**

DIRECTION OF EVOLUTION

KINGDOM PLANTAE

- It contains all photosynthetic eukaryotic multicellular plants and their non-photosynthetic relatives.
- Mode of nutrition is mainly **autotrophic,** hence called **producers.** Some of the plants are **heterotrophic,** of which most are **parasitic** and a few are **saprobes.**
- Cell wall is **cellulosic.** Food reserve is usually **starch** and **fat.**
- Reproduction is both asexual and sexual.

Tracheophyta
- **Angiospermae**
- **Gymnospermae**
- **Pteridophyta**

Bryophyta (Mosses and liverworts)

Phaeophyta (Brown algae)

Rhodophyta (Red algae)

Chlorophyta (Green algae)

KINGDOM FUNGI

- It contains **achlorophyllous,** spore producing, multicellular or multinucleate eukaryotic organisms.
- They have **heterotrophic** with absorptive type of nutrition *i.e.,* either saprobic or parasitic.
- Cell wall contains **chitin** and noncellulosic polysaccharides. The cellular organisation is two envelope type.
- Reproduction is both asexual and sexual.

Basidiomycota (Club fungi)

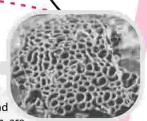
Ascomycota (Sac fungi)

Deuteromycota (Fungi imperfecti)

Zygomycota (Conjugation fungi)

Oomycota (Water molds)

Myxomycota (Slime molds)



KINGDOM ANIMALIA

- It has maximum number and most diverse types of organisms.
- Organisms are multicellular eukaryotes. Body form is regular. Cellular, tissue and organ system levels of organisation occurs in different groups. A **cell wall is absent.** The organisms have **holozoic** or **ingestive** type of nutrition. A few animals are, however, parasitic. They live on or inside the bodies of other eukaryotes.
- Reproduction is mostly sexual.

Chordata (Chordates)

Mollusca (Molluscs)

Echinodermata (Echinoderms)

Arthropoda (Arthropods)

Annelida (Segmented worms)

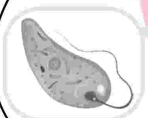
Nemathelminthes (Roundworms)

Platyhelminthes (Flatworms)

Cnidaria (Coelenterates)

Porifera (Sponges)

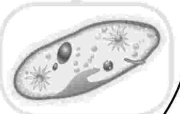
Euglenophyta (Euglenoids)



KINGDOM PROTISTA

- It includes all **unicellular** and **colonial eukaryotes.** Most of them are aquatic organisms forming **plankton.**
- They have diverse modes of nutrition – photosynthetic, saprobic, parasitic, ingestive or holozoic, etc. Genetic material is organised in the form of nucleus. DNA is associated with histone. The aerobic forms possess mitochondria and other membrane bound organelles. Flagella, if present are 11-stranded with 9 + 2 organisation of microtubules.
- These organisms with flexible lifestyles justifies the erection of the intermediate eukaryotic Kingdom Protista. It is a connecting link between prokaryotic Monera and the other eukaryotic kingdoms.

Sporozoa (Sporozoans)



Ciliophora (Ciliates)

Zoomastigina (Animal flagellates)

Chrysophyta (Diatoms and related algae)

Pyrrophyta (Dinoflagellates)

Primitive eukaryotic flagellate

Cyanobacteria (Blue green algae)

Eubacteria (True bacteria)

Archaebacteria (Ancient bacteria)

KINGDOM MONERA

- It includes basically unicelluar, microscopic prokaryotes and the most primitive of living forms with different modes of nutrition *i.e.,* – **saprobic, parasitic, chemoautotrophic, photoautotrophic** and **symbiotic.**
- Cell wall comprises of **peptidoglycan** and polysaccharides other than cellulose. Cells have one envelope type of organisation but **internal compartmentalisation is absent.**
- If present, flagella are single stranded, genetic material is not organised into a nucleus, DNA is naked *i.e.,* without histone, all membrane bound cell organelles are absent. Sexual reproduction is absent as meiosis does not occur.

Viruses

- Viruses are intermediate between living and non-living entities. These act as **obligate parasites**, *i.e.,* inert outside the host cell.
- They do not grow, divide or reproduce like typical living organisms, rather reproduce using host machinery.
- Viruses are thus described as a nucleoprotein entity which is able to utilise the synthetic machinery of a living cell of another organism for its multiplication and division.
- They resemble living organisms in possessing genetic material and organic macromolecules and showing mutations.
- They are responsible for a number of infectious diseases in plants, animals and humans.

CONCEPT MAP

KINGDOM FUNGI

Fungi is a large kingdom comprising of about 5100 genera and more than 50,000 species. They are achlorophyllous, heterotrophic, spore forming, eukaryotic organisms with thalloid body made up of hyphae (together constituting mycelium). They are **cosmopolitan** in distribution. Some fungi occur in fresh or marine water, others are terrestrial and still others are air borne. The study of fungi is known as **mycology.**

NUTRITION

- They may be **obligate parasites** (obtain food from host plants and die with the death of host) or **facultative saprophytes** (usually parasitic but able to absorb food from decaying host plant as well), **obligate saprophytes** (obtain food from decaying organic matter) or **facultative parasites** (usually saprophytes but can live parasitically under some conditions).

REPRODUCTION

- Fungi may reproduce by vegetative, asexual and sexual means.

Vegetative

Budding
Small outgrowths from vegetative body, cut off and mature to form new individuals, *e.g.*, yeast

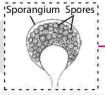
Fission
Splitting of vegetative cells into two daughter cells.

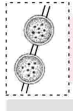
Fragmentation
Fragments of vegetative hyphae develop into new individual.

Asexual

Zoospores
Uniflagellate or biflagellate, thin walled, uninucleate structures formed in zoosporangia, *e.g., Phytophthora, Albugo.*

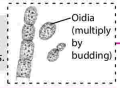
Sporangiospores
Nonflagellate spores that develop inside sporangia, *e.g., Mucor, Rhizopus.*





Chlamydospores
Thick-walled perennating spores which develop at places along the hyphae by accumulation of protoplasm, rounding off and secretion of thick wall.

Oidia
Usually formed under conditions of excess water, sugar and certain salts, *e.g., Rhizopus.*

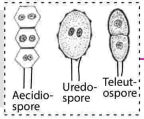


Conidia
Nonmotile, thin-walled, exogenous spores, produced in chains upon the tip of hypha called **conidiophore**, *e.g., Aspergillus, Penicillium.*

Ascospores
Nonmotile meiospores which are produced inside special sacs called **asci** and are characteristic of Class Ascomycetes.

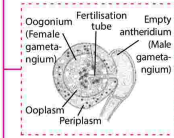
Basidiospores
Nonmotile meiospores formed exogenously on short outgrowths of club-shaped structure called basidium and are characteristic of Class Basidiomycetes.

Binucleate spores
Dikaryotic spores meant for multiplying the dikaryotic mycelium, *e.g.,* aecidiospores, uredospores in *Puccinia.* Another type of dikaryotic spore is teleutospore or teliospore.



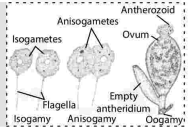
Sexual

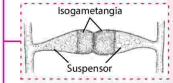
Sexual reproduction takes place by following processes:



Gametangial contact
Here gametes are never released from gametangia, instead the male and female gametangia come in close contact with the help of a fertilisation tube, through which one or more male nuclei migrate to the female gametangium. *E.g., Pythium*

Planogametic copulation
This involves fusion of two naked motile gametes (planogametes). Based upon the nature and structure of gametes, it is of three types: isogamy, anisogamy and oogamy.





Gametangial copulation
This process involves fusion of the entire contents of two compatible gametangia, resulting in karyogamy. *E.g., Mucor.*

Somatogamy
Here sex organs are not at all formed, but two vegetative hyphae or cells take over the sexual function and fuse together. *E.g., Morchella, Peziza.*

Spermatisation
In some advanced genera, the sexual process is accomplished by minute spore-like spermatia (male gametes) and specialised receptive hyphae (female gametes). The spermatia are carried by air, water or insects to the receptive hyphae. The contents of the spermatium enter the receptive hyphae through a pore.

CLASSIFICATION

- Many botanists have classified fungi in different ways.
- **Martin's** (1961) classification of fungi is most prevalent. He classified fungi into Myxomycotina (Slime molds) and Eumycotina (True fungi).
  Martin further divided Eumycotina into the following classes:

Phycomycetes

- The mycelium is aseptate and coenocytic.
- The sporangia has innumerable sporangiospores (zoospores or aplanospores) formed endogenously.
- Sexual reproduction is oogamous in Oomycetes, and isogamous in Zygomycetes.
- Biflagellate motile cells (zoospores) are produced by many species.
- The zygote is unicellular and simple.
- *E.g., Albugo, Phytophthora* (Oomycetes), *Rhizopus, Mucor* (Zygomycetes).

STRUCTURE

- Fungi range from unicellular, uninucleate forms like yeast and *Synchytrium* to thread-like structure called **mycelium** which is made up of a net like mass of tubular filaments called **hyphae**. The hypha is usually branched, tube like structure, having protoplasm with reserve food and bounded by a wall of **chitin**, a nitrogen containing polysaccharide $(C_{22}H_{54}N_4O_{21})_n$.
- The protoplasm of the hypha may be continuous without cross walls, called **aseptate hypha** or may have transverse partitions or septa, known as **septate hypha**. Septa are seldom complete as they are perforated and may contain plasmodesmata or central pores. When central septal pore possesses a barrel-shaped inflation, as in many basidiomycetes, it is known as **dolipore septum**.
- A membranous vesicle called **lomasome** is found attached to plasma membrane.

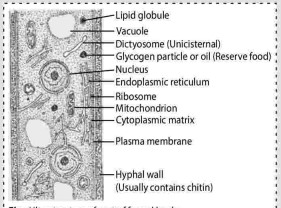


Fig.: Ultrastructure of part of fungal hypha

- In some fungi, hyphae may structurally modify in response to functional needs as:
  (a) **Prosenchyma :** It is formed when the component hyphae lie more or less parallel to one another and unite to form a rather loosely interwoven structure where their individuality is not lost.
  (b) **Pseudo-parenchyma :** It is formed when the hyphae become closely interwined, forming a tissue which consists of hollow tubes spread in all directions. These lose their individuality.
  (c) **Rhizomorph :** It is a thick strand or root-like aggregation of somatic hyphae which lose their individuality. The entire mass behaves as an organised unit and have higher infection capacity.
  (d) **Sclerotium :** It is a compact globose structure, formed by the aggregation and adhesion of hyphae.
  (e) **Appressorium :** It is a terminal, simple or lobed, swollen structure of germ tubes or infecting hyphae, found in many parasitic fungi.
  (f) **Haustorium :** These are intracellular, absorbing structures of obligate parasites meant for absorbing food material from the host. They may be variously shaped and secrete specific hydrolysing enzymes.

Ascomycetes

- The mycelium consists of septate hyphae, possessing central or septal pores. Motile structures do not occur in the life cycle.
- In majority of Ascomycetes, the common mode of asexual reproduction is through the formation of conidia.
- Sexual reproduction takes place through fusion of sex cells, somatic cells, gametangial contact between an antheridium and ascogonium and autogamy.
- Karyogamy is delayed after plasmogamy. Hence, a new transitional phase called dikaryophase appears in the life cycle. The cells of dikaryophase are called dikaryotic cells as each cell possesses two nuclei (n + n).
- Some dikaryotic cells function as ascus mother cells. **Ascus** is a sporangial sac peculiar to Ascomycetes. 4-8 haploid meiospores named ascospores are produced internally in each ascus.
- The asci may occur freely or get aggregated with dikaryotic mycelium to form fructifications called **ascocarps**.
- *E.g.,* Yeast, *Aspergillus, Penicillium, Claviceps,* morels and truffles.

Basidiomycetes

- Basidiomycetes are the most advanced fungi and considered among the best decomposers of wood.
- Motile structures or cells are absent. Mycelia are of two types, primary and secondary.
- Karyogamy is delayed after plasmogamy. A new transitional phase called dikaryophase appears in the life cycle. It produces dikaryotic secondary mycelium. Secondary mycelium is long lived, profusely branched septate hyphae possessing dolipores.
- Hook-shaped outgrowths called **clamp connections** are found on the sides of septa which are meant for proper distribution of dikaryons at the time of cell division.
- Karyogamy and meiosis occur in club-shaped structures known as **basidia**. A basidium commonly produces four meiospores or basidiospores exogenously at the tip of fine outgrowths called **sterigmata**.
- The fungi may or may not produce fructifications called **basidiocarps** that vary in size from microscopic to macroscopic forms.
- *E.g., Puccinia, Ustilago, Agaricus,* bracket fungi, etc.

Deuteromycetes

- Deuteromycetes is an artificial class of fungi which has been created to include all those fungi in which sexual stage is either absent or not known.
- Some of the deuteromycetes are unicellular like yeast.
- The mycelium is usually septate. Coenocytic forms are not known.
- Asexual reproduction often occurs by conidia along with some other types of spores.
- It is believed that most members of deuteromycetes are actually ascomycetes in which sexual reproduction is either absent or yet to be discovered.
- *E.g., Colletotrichum, Helminthosporium, Trichoderma.*

CONCEPT MAP

LICHENS

Lichens are composite or **dual organisms** representing an intimate symbiotic relationship between algae and fungi (De Bary, 1879). The algal component of lichen is known as **phycobiont** whereas the fungal component is known as **mycobiont**. The fungal component predominates algal component, such an association is known as **helotism** (Crombic, 1885). There are about 400 genera and 1600 species of lichens. They usually grow on bark of trees, dry logs **(corticolous)**, bare rocks **(saxicolous)** or soil **(terricolous)**, etc.

Classification

On the basis of fungal component

Ascolichens
The fungal component of these lichens is a member of Class Ascomycetes. They are called **gymnocarpeae** if the fruiting body is a disc like apothecium (also known as discolichens, *e.g., Parmelia*). They are called **pyrenocarpeae** if the fruiting body is a flask shaped perithecium (also known as pyrenolichens, *e.g., Dermatocarpon*).

Basidiolichens
The fungal component of these lichens is a member of Class Basidiomycetes. Genera like *Corella* and *Dictyonema* belong to this group.

Deuterolichens
The fungal component of these lichens belongs to Class Deuteromycetes.

On the basis of external morphology

Crustose lichen
These are encrusting lichens with an inconspicuous, thin and flat thallus, firm in texture. The thallus is very closely adhered to the substratum and provides a crust-like appearance.
Examples: *Graphis, Haematomma, Lecanora.*


Crustose lichen

Foliose lichen
These lichens are flat with leaf-like and lobed thallus attached to the substratum with the help of rhizoid - like **rhizines**.
Examples: *Parmelia, Physcia.*


Foliose lichen

Fruticose lichen
Shrub-like, cylindrical and branched thallus that grow erect or hang from the substratum with the help of a basal mucilagenous disc.
Examples: *Alectonia, Cladonia.*


Fruticose lichen

Internal Structure

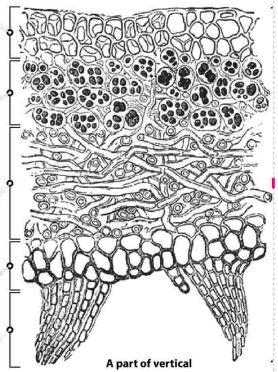
Upper cortex
Composed of compactly interwoven fungal hyphae arranged at right angles to the surface of thallus, usually lacking intercellular spaces (if present, then filled with gelatinous substance).

Algal zone
This layer is composed of green or blue green algae. The algal cells remain embedded in the tangled network of fungal hyphae. Sometimes algal cells and fungal hyphae are uniformly distributed throughout the thallus **(homoisomerous)** whereas sometimes algal cells form a distinct layer within thallus **(heteromerous)**.

Medulla
Central part of thallus, comprised of loosely interwoven fungal hyphae with large spaces between them.

Lower cortex
Composed of compactly arranged fungal hyphae running parallel or perpendicular to surface of thallus.

Rhizines
Some hyphae of lower cortex descend down and help in attachment of thallus to substratum. These are known as rhizines.

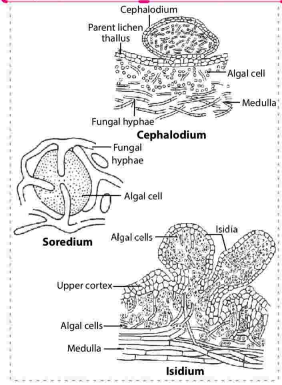

A part of vertical section of lichen

Reproduction

Lichens reproduce both by asexual and sexual means.

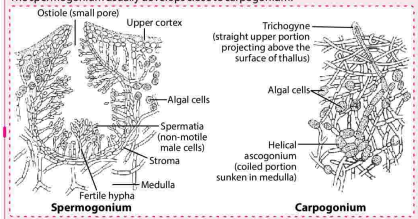
Asexual reproduction

Asexual reproduction occurs by following structures:
(i) **Cephalodium :** These appear as small, hard, dark-coloured, gall-like swellings on the free surface of some lichen thalli. They contain the same fungal hyphae as in the thallus but the algal component is always different.
(ii) **Soredium :** Small bud-like outgrowths over the upper surface of thalli, containing one or few algal cells closely enveloped by a weft of fungal hyphae. Both fungus and alga are same as in parent thallus.
(iii) **Isidium :** These are small outgrowths on the upper surface of the lichen thallus each consisting of an outer cortical layer made up of fungal cells followed by an algal layer of the same kind as in the thallus.

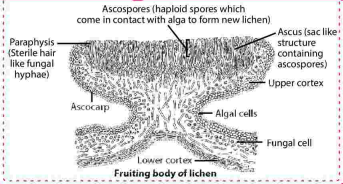


Sexual reproduction

In lichens, the process of sexual reproduction is performed only by the fungal component. The female sex organs are known as **carpogonia**. The male sex organs are known as **spermogonia**. A carpogonium is differentiated into a basal coiled ascogonium and an elongated multicellular trichogyne. Each spermogonium is a flask- shaped receptacle immersed in a small elevation on the upper surface of thallus. The spermogonium usually develops close to carpogonium.



Spermatia adhere to the projected part of sticky trichogyne. On dissolution of the walls between them the nucleus of spermatium migrates into the carpogonium through trichogyne. The male nucleus fuses with the female nucleus. Several branched ascogenous hyphae develop from the base of the fertilised ascogonium. The terminal binucleate cell of ascogenous hypha develops into an ascus. The two nuclei within the ascus fuse to form a diploid nucleus which forms eight haploid daughter nuclei meiotically, each metamorphosing into an ascospore. The ascospores are hyaline and green or brown in colour. They are released gradually from the ascus, and on coming in contact with a suitable alga, form a new lichen thallus.



Economic Importance

(i) **As food :** Species of *Lecanora, Parmelia, Umbilicaria* and *Cetraria islandica* are used as food in many parts of the world. *Umbilicaria esculenta* is a delicacy in Japan, while the species of *Parmelia* are used as curry powder in India.
(ii) **As medicine :** *Parmelia perlata* is specially useful in dyspepsia and in the treatment of snake and scorpion bites. *Cladonia, Cetraria* and *Pertusaria* are used in intermittent fever. *Cladonia pyxidata* is useful in whooping cough. *Usnea* sp. are used to stop bleeding. Erythrin, obtained from *Roccella montagnei*, is used in angina. *Lobaria pulmonaria* and *Cetraria islandica* are used in tuberculosis and other lung diseases.
(iii) **As dyes :** Red and purple dyes are obtained from *Ochrolechia androgyna* and *O. tartarea*. **Orchil**, a blue dye is obtained from some lichens (*e.g., Cetraria islandica*). *Parmelia omphalodes* is the source of a brown dye. **Litmus**, an important acid-base indicator dye in chemical laboratories, is obtained from *Roccella montagnei* and *Lasallia pustulata*.
(iv) **In tanning industry :** *Cetraria islandica* and *Lobaria pulmonaria* are used as tanning agents in leather industries.
(v) **In cosmetics :** *Evernia* and *Ramalina* are the source of essential oils, used in the manufacture of cosmetic soaps. *Ramalina calicaris* is used for whitening hair in wigs. *Pseudevernia furfuracea* and *Evernia prunastri* are widely used in the manufacture of perfumes.

Ecological Significance

Lichens are pioneer plants in ecological succession, which help in colonisation of bare rocky habitats. They secrete some organic acids which disintegrate rocks and form soil and substratum for subsequent establishment of other vegetation types. Lichens can be used as air pollution indicators especially of the concentration of sulphur dioxide in atmosphere. Several lichens are also harmful to us. They cause a considerable loss due to etching of glass surfaces and marble stones. Some lichens, such as *Letharia vulpina* (wolf moss) are poisonous.

CONCEPT MAP

MORPHOLOGY OF ROOTS

- Root constitutes the lower part of plant axis which develops from radicle and typically grows towards gravity.
- Roots are usually non-green, underground, cylindrical or sub-cylindrical, and tapering. They do not have nodes, internodes and leaves.
- Root branches develop from interior (usually pericycle) of the parent root. Such an origin is called endogenous.

Parts of a typical root

A typical root possesses four parts - root cap, zone of cell formation, zone of cell elongation and zone of cell maturation.

(i) **Root cap:** It is a thimble-shaped or cap-shaped parenchymatous, multicellular structure which covers the apex of root. It provides protection to the young apical cell against soil particles.

(ii) **Zone of cell formation (Region of meristematic activity):** It is subterminal. The cells of this region are thin walled, with dense cytoplasm and large nucleus. These cells are in active state of division and thus their number increases continuously.

(iii) **Zone of cell elongation :** This region is situated just above the meristematic zone. The cells of this region lose the power of division and elongate rapidly. This increases length of root.

(iv) **Zone of cell maturation :** The cells of this region are differentiated into permanent tissues depending upon the functions they have to perform. From this region some of the epidermal cells form fine, delicate, thread like structure called root hairs which absorb water and minerals from the soil.

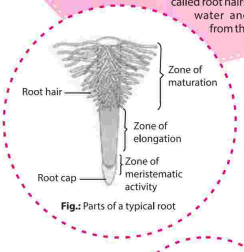


Fig.: Parts of a typical root

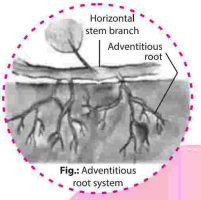


Fig.: Adventitious root system

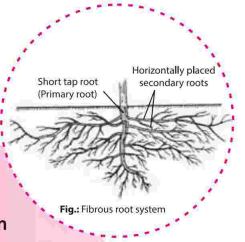


Fig.: Fibrous root system

Types of root system

Root systems are of three types: tap root system, fibrous root system and adventitious root system.

(i) **Tap root system :** In majority of dicots, direct elongation of the radicle leads to the formation of primary root which bears lateral roots of several orders that are referred to as secondary, tertiary roots, etc. The primary roots and its branches constitute the tap root system.

(ii) **Fibrous root system :** In monocotyledons, the primary root is short lived and is replaced by a large number of roots. These roots originate from base of stem and constitute the fibrous root system.

(iii) **Adventitious root system :** Adventitious roots develop from any part of the plant other than radicle. These roots constitute adventitious root system.

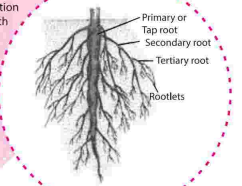


Fig.: Tap root system

Modifications of root

In addition to normal work of anchorage, absorption of water and minerals, roots perform some special functions for which they get variously modified.

Storage of food

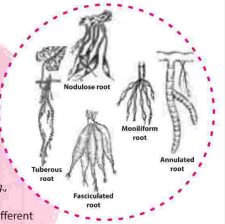
Tuberous : These roots arise from nodes of stem and become tuberous and fleshy for storage of food, *e.g., Ipomoea*.

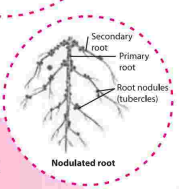
Fasciculated : These roots arise in bunches from lower nodes of stem and become thick and fleshy, *e.g., Asparagus*.

Moniliform : These roots are swollen at regular intervals like beads of necklace, *e.g., Momordica*.

Annulated : In these roots swelling at different places takes place in such a way that closely placed ring like structures are formed, *e.g., Psychotria*.

Nodulose : In these roots apical portion swell up, *e.g., Curcuma amada*.





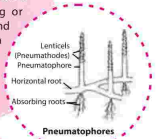
Nodulated root

Nodulated roots

The secondary, tertiary roots, sometimes primary roots also develop numerous small or large irregular swellings called nodules or tubercles. These are found in leguminous plants and harbour numerous nitrogen fixing bacteria.

Pneumatophores

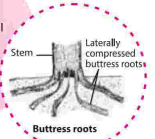
They are breathing or respiratory roots, found in plants growing in mangroves or saline swamps, *e.g., Rhizophora*.



Pneumatophores

Buttress roots

They are horizontal roots that arise jointly from the bases of tap root and the trunk. They provide extra support, *e.g., pipal*.



Buttress roots

Modifications of tap roots

Fleshy tap roots

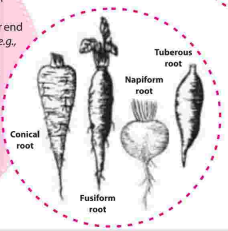
Tap roots become swollen and fleshy with stored food. These are of following types:

Conical : These roots get thicker on the upper end to store food and tapering at the lower end, *e.g.,* carrot.

Fusiform : These roots get thicker in the middle and tapering on both ends, *e.g.,* radish.

Napiform : These roots get very much swollen and spherical at the upper end for storage of food and taper downwards into a thread like structure, *e.g.,* turnip.

Tuberous : These roots get swollen in any portion, thus they do not have a regular shape, *e.g., Mirabilis*.



Modifications of adventitious roots

Vital functions

Assimilatory roots : Roots of some plants develop chlorophyll and perform photosynthesis, *e.g., Tinospora*.

Haustorial roots : These roots occur in parasites for absorbing nourishment from the host. They are also called sucking roots or suckers, *e.g., Cuscuta*.

Epiphytic roots : These roots are found in epiphytes. They hang in air. These roots have spongy tissue called velamen for absorption of atmospheric moisture, *e.g.,* orchids.

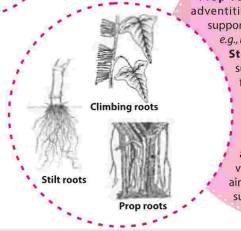
Contractile roots : These roots can shrink 60-70% of the original length which brings an underground organ to its proper depth in soil, *e.g., Crocus*.

Mechanical support

Prop roots : They are thick pillar-like adventitious roots which grow from and support heavy horizontal branches of trees. *e.g., Ficus benghalensis*.

Stilt roots : They are short but thick supporting roots which develop obliquely from basal nodes of stem, *e.g.,* sugarcane.

Climbing roots : They are non-absorptive adventitious roots which are found in climbers. They may arise from nodes, internodes or both *e.g.,* betel, Ivy. The apices of these roots produce a viscous substance which dries in the air and so the roots get attached to substratum.



CONCEPT MAP

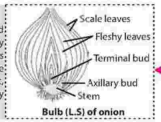
VEGETATIVE PROPAGATION IN PLANTS

Vegetative propagation is the regeneration of new plants from vegetative parts of parent plant. It includes all those processes of propagation in which a part of the plant body is separated from the parent plant and gives rise to a new individual without any obvious changes in the protoplast. All the plants developed by vegetative propagation are genetically identical to their parent plants.

NATURAL METHODS

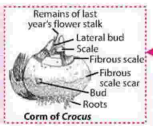
Propagation by Stem

Bulb
Short and thickened underground stem axis represented by a slightly conical disc with fleshy leaves surrounding a terminal bud at the centre of disc. Onion, tulip, garlic etc.,commonly propagate by bulb.



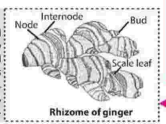
Bulb (L.S) of onion

Corm
Condensed form of rhizome which grows vertically down. Internodes are usually reduced and one or more axillary buds are present in the axil of scale leaves. *Colocasia, Gladiolus, Crocus,* etc., propagate through corm.



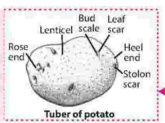
Corm of *Crocus*

Rhizome
They are thick, prostrate and branched stems which grow horizontally. Distinct nodes and internodes are present. Nodes bear small scale leaves with buds. Ginger, turmeric, *Canna*, etc., propagate by means of rhizomes.



Rhizome of ginger

Tuber
It is an underground stem modification for reserve food accumulation. Eyes or axillary buds are present on the surface which give rise to new plantlets. Potato, *Caladium*, etc., commonly propagate by tuber.



Tuber of potato

Underground stem

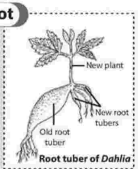
Propagation by Leaf

Foliar buds are produced on leaf margins of many plants which can grow into new plants. When such leaves fall on the ground the buds germinate and give rise to new plants, *e.g., Bryophyllum, Kalanchoe,* etc.

Foliar buds in *Bryophyllum*

Propagation by Root

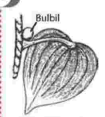
Tap roots of some plants develop adventitious buds to form new plants, *e.g., Dalbergia.* In some plants like sweet potato and *Dahlia,* root tubers develop adventitious buds which develop into new plant.



Root tuber of *Dahlia*

Propagation by Bulbil

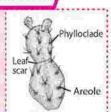
In *Globba bulbifera,* some flowers in the lower part of the inflorescence are modified into small multicellular structures, called **bulbils**. They fall on the ground and grow into new plants. In American aloe, (*Agave sisalana*), reproductive buds (bulbils) often take the place of many flowers on the inflorescence axis. Bulbils are also produced in the leaf axil of wild yam (*Dioscorea bulbifera*) and *Lilium bulbiferum.*



Bulbil of *Dioscorea bulbifera*

Aerial stem

Phylloclades are fleshy, green, flattened or cylindrical stem branches. Each segment of stem can form a new plant on breaking off, *e.g., Opuntia.*



Phylloclade of *Opuntia*

Subaerial stem

Some subaerial stem modifications also take part in vegetative propagation. **Runner** is a slender creeping stem with long internodes. Nodes bear axillary buds, scale leaves and adventitious roots. Runners break off and grow into individual plants, *e.g., Oxalis, Cynodon,* etc. **Stolons** are arched horizontal branches which develop into new plants where they touch the ground, *e.g.,* strawberry. **Offset** is a short runner that is one internode long, generally found in aquatic plants, *e.g., Eichhornia.* **Suckers** are slender subaerial branches which develop from base of aerial shoot. Initially they grow horizontally but soon grow obliquely upwards forming a leafy shoot, *e.g.,* mint.

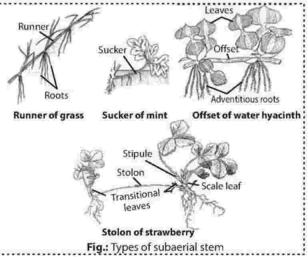


Fig.: Types of subaerial stem

ARTIFICIAL METHODS

Layering

It is the method of inducing root formation in stem while it is still attached to the parent plant. It is of following types :

(i) **Tip layering :** In this method, tip portion of the shoot is bent and buried in the soil. *E.g.,* black raspberry.

(ii) **Serpentine layering :** In this method, long slender shoot is bent and laid to the ground, covered with soil at short regular intervals so as to form many plants. *E.g., Clematis.*

(iii) **Trench layering :** In this method, long shoot is placed in trench leaving the apical portion exposed. Roots are produced at each node on the lower side and shoot emerges on the upper side. *E.g.,* walnut, mulberry.

(iv) **Simple layering :** In this method, rooting is induced on a soft stem. It is defoliated and a small injury is made on it. After that it is pegged in the soil to develop adventitious roots. Later on, the layer is separated and planted. *E.g.,* jasmine, grapevine.

(v) **Air layering or gootee :** In this method, rooting is induced in aerial hard branches. The stem is girdled and covered with moist moss or cotton. Water is added to it along with small quantity of root promoting hormones. After 2-3 months roots appear and shoot is then cut below the cotton bandage and replanted. *E.g.,* litchi, pomegranate.

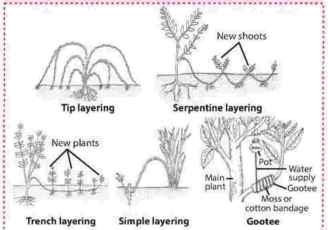


Fig.: Types of layering

Cutting

Any part of the plant (stem, root or leaf) that produces roots when put into the soil and gives rise to a new plant is called cutting. It can be done in following ways :

(i) **Root cutting :** The pieces of roots are used to artificially propagate new plants, *e.g.,* lemon, orange, etc.

(ii) **Stem cutting :** 20-30 cm long stem cuttings are used to propagate both herbaceous and woody plants. Their lower ends are dipped in root promoting hormones for several minutes before planting, *e.g.,* rose.

(iii) **Leaf cutting :** In this technique, leaf is transversely cut into two or three parts and leaf cuttings are vertically planted in soil, *e.g., Sansevieria.*

Grafting

Grafting is the technique of joining together parts of two different plants in such a manner that they unite and later develop as a composite plant. Various techniques of grafting are as follows :

(i) **Tongue grafting:** Oblique cut is given to both stock and scion (of same diameter) and they are tied together.

(ii) **Crown grafting:** Stock has larger diameter than scion. Many slits are formed on the sides of stock and scions are inserted into them and bandaged.

(iii) **Wedge grafting :** V-shaped notch is given to stock and wedge like cut is given to scion (both of same diameter).

(iv) **Side grafting :** V-shaped notch is given to stock at one side and scion is inserted in it. Stock has larger diameter than scion.

(v) **Approach grafting :** Two independently growing plants are brought together. Their shoots are given cuts at the same level and united.

(vi) **Bud grafting :** In bud grafting, scion consists of a single bud accompanied with a portion of living tissue. It is inserted into a T-shaped incision on the stock treated with grafting wax and bandaged, *e.g.,* apple, peach.

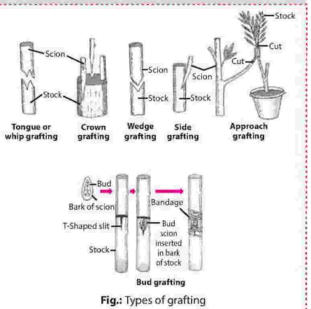


Fig.: Types of grafting

Micropropagation

The technique of propagating plants by culturing cells, tissues and organs is known as micropropagation. It is popularly known as **tissue culture**. Methods of micropropagation are callus culture, suspension culture, embryo culture, anther culture, protoplast culture, etc. Laboratory culturing ultimately results in formation of large number of plantlets, *e.g.,* orchids, Carnation, etc.

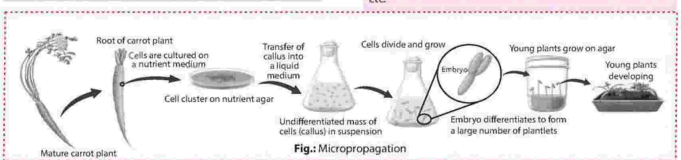


Fig.: Micropropagation

CONCEPT MAP

MORPHOLOGY OF STEM

Stem is the ascending part of the plant axis which develops from the plumule of the embryo. It grows by means of a terminal bud and shows distinction into nodes and internodes. Leaves and stem branches develop exogenously from it.

Branching of stem

Branching of the stem is of two types: 1. Dichotomous branching and 2. Lateral branching.

1. Dichotomous branching : The growing point gets divided into two in the region of branching, *e.g., Asclepia syriaca, Pandanus.*

2. Lateral branching : Branching occurs by exogenous growth of lateral buds. It is further divided into two main types: (i) Racemose branching and (ii) Cymose branching.

(i) **Racemose or monopodial branching :** Terminal bud continues its activity indefinitely and the lateral branches are borne in an acropetal succession, *e.g., Eucalyptus, Casuarina.*

(ii) **Cymose or sympodial branching :** The terminal bud, after forming a small portion of the axis, either stops its activity or gets modified into a flower, tendril, thorn etc. Lateral branches are borne in basipetal succession. Further growth of the axis is continued by one or more axillary branches. Accordingly, it is of three types: (a) **Uniparous or monochasial** – Further growth is continued by a single axillary branch. The successive branches may develop either on both the sides *i.e.,* scorpioid (*e.g.* grapevine) or on one side only *i.e.,* helicoid (*e.g., Saraca*). (b) **Biparous or dichasial** – Further growth is continued by two axillary branches, *e.g., Viscum, Mirabilis etc.*

(c) **Multiparous or polychasial :** Growth is continued by whorl of three or more axillary branches, *e.g., Euphorbia, Croton* etc.

Unbranched stem is called caudex, *e.g.,* palm, sugarcane.

Buds and their classification

A bud represents a condensed immature or embryonic shoot possessing a growing point enveloped by closely placed immature leaves.

Classification of buds :

(I) On the basis of nature/ structure : (i) **Vegetative buds** (give rise to leafy shoots only), (ii) **Floral buds** (give rise to flowers), (iii) **Mixed buds** (give rise to both vegetative and floral branches).

(II) On the basis of position: (i) **Normal buds** - These are borne on stem either terminally or laterally. Accordingly these may be **apical/terminal buds, *e.g.,*** cabbage; **lateral buds** which may be axillary (*e.g.,* rose), accessory (*e.g. Cucurbita*), extra -axillary (*e.g., Solanum nigrum*), (ii) **Adventitious buds** - When a bud grows from a position other than normal, it is called adventitious bud. These may be **epiphyllous/foliar** buds *e.g. Bryophyllum*; **cauline buds** *e.g., Duranta* and **radical buds** *e.g. Ipomoea.*

(III) On the basis of activity - (i) **Active buds** (These become active as soon as they are formed), (ii) **Dormant buds** (These remain inactive for short or long periods and are commonly covered by protective scales, *e.g. Ficus*), (iii) **Modified buds -** *e.g.,* bulbils in *Dioscorea,* turions in *Potamogeton,* tendrils in *Passiflora* and thorns in *Duranta,* etc.

Diverse forms of stem

Stems of flowering plants attain diverse forms to perform various functions. They are grouped into three broad categories: reduced stems, erect stems and weak stems.

1. Reduced stems – Stem is reduced to a small disc and nodes and internodes are not distinguishable, *e.g.,* in raddish, carrot, *Lemna, etc.*

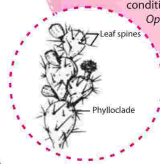
2. Erect stems – Stems are sufficiently strong to remain erect or upright without any external support. Erect stems with swollen nodes or jointed stems (**Culms** *e.g.,* bamboo), unbranched erect stems (**caudex or columnar** *e.g. Cocos nucifera*), branched erect stems (**Excurrent** *e.g., Eucalyptus,* **Deliquescent** *e.g. Dalbergia*).

3. Weak stems : The stems are thin, soft and weak. These may be upright or prostrate. (i) **Upright weak stems :** These are further of two types – Twiners and climbers. **Twiners :** The stems are long, stender, flexible and sensitive. They twin or coil around an upright support on coming in its contact, *e.g., Convolvulus, Lablab.* **Climbers :** The stems are weak and climb up the support with the help of some clasping or clinging structures. Accordingly, these may be (a) **Root climbers** *e.g.,* Ivy (b) **Tendril climbers** *e.g., Passiflora, Gloriosa.* (c) **Scramblers** *e.g., Bougainvillea* (d) **Lianas** *e.g., Bauhinia.* (ii) **Prostrate or sub-aerial weak stems:** These spread over the ground for proper exposure of leaves. These are of two types – Trailers and creepers. Trailers do not root at intervals, *e.g., Euphorbia prostrata.* Creepers root at intervals and take part in vegetative propagation. These may be runners, stolons and offsets. (a) **Runners :** They are special narrow, green, above ground horizontal or prostrate branches which develop at the bases of erect shoots called crowns. The nodes bear scale leaves and axillary buds, which grow to form new crowns *e.g., Cynodon dactylon, Centella* etc. (b) **Stolons :** These are arched runners which can cross over small obstacles, *e.g.,* strawberry, jasmine etc. (c) **Offsets :** These are one internode long runners usually found in rosette plants at the ground or water level, *e.g., Eichhornia, Pistia* etc.

Modifications of stem

Aerial stem modifications

Phylloclades These are the green, photosynthetic stems of unlimited growth, in which true leaves are caducous. These help the plants to grow in xerophytic conditions, *e.g., Opuntia.*

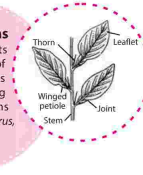


Cladodes These are one to two internode long stem branches which are photosynthetic and have limited growth, *e.g., Ruscus aculeatus.*

Stem tendrils These may be axillary (*e.g. Passiflora*), extra-axillary (*e.g. Cucurbita*), leaf opposed (*e.g.* grapevine), inflorescence tendrils (*e.g., Antigonon*) etc.

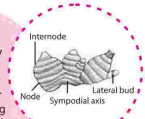
Thalamus It forms the broadened tip of the pedical or floral stalk. It bears sepals, petals, stamens and carpels.

Stem thorns A thorn represents an axillary branch of limited growth. Thorns are deep seated having vascular connections with stem , *e.g., Citrus, Duranta* etc.

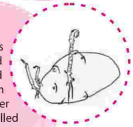


Underground stem modifications

Rhizome It is a perennial, fleshy underground stem which grows indefinitely producing new leaves or aerial shoots during favourable season. It may be **rootstock rhizome** (*e.g., Dryopteris*) or **Straggling rhizome** (*e.g., Zingiber*).



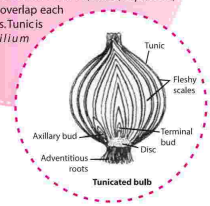
Tuber It represents the swollen end of a specialised underground stem branch. Each tuber bears nodes called eyes, *e.g., Solanum tuberosum*



Bulb It consists of a highly reduced discoid stem and several fleshy scales enclosing a terminal bud. Bulbs are of two types – Tunicated and scaly.

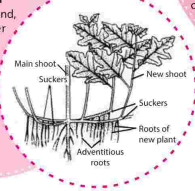
(i) Tunicated bulb : In *Allium cepa* (onion), the scale leaves occur in a concentric manner forming a series of rings and the rings are surrounded by a common tunic (**Simple tunicated bulb**). In *Allium sativum* (garlic), the fleshy scales represent buds and are called **bublets** or **cloves**, which occur in irregular concentric rings. Each ring is surrounded by a white tunic and each bulblet has its own thick white tunic (**Compound tunicated bulb**).

(ii) Scaly bulb : Fleshy scales are narrow, small, separated, loosely arranged and overlap each other at their margins. Tunic is absent, *e.g., Lilium bulbifera.*



Corm It is short, thick, fleshy, usually unbranched, spherical or subspherical specialised underground stem produced **annually** and growing **vertically** in soil. Circular nodes bear scale leaves and one or more axillary buds, *e.g., Amorphophallus, Colocasia* etc.

Sucker It is an under-ground, non-green slender branch of the stem which arises from the axillary bud of the underground part of aerial stem, *e.g., Chrysanthemum.*



CONCEPT MAP

MORPHOLOGY OF LEAF

Leaf is an important vegetative organ of plant as it is specialised to perform photosynthesis. It is a green lateral flattened outgrowth borne on the node of a stem or stem branch and bears a bud in its axil.

Parts of a leaf

A typical leaf consists of three parts - leaf base, petiole and lamina. **Leaf base** is the basal part of the leaf by which it is attached to the node of the stem. Different plants have different types of leaf bases *viz.* pulvinus, *e.g.,* pea; sheathing, *e.g., Zea mays*; decurrent, *e.g., Crotolaria* and amplexicaul, *e.g., Polygonum*. Leaves of some plants have lateral appendages on each side of leaf base, known as **stipules** which may be caducous, deciduous or persistent. **Petiole** is the leaf stalk that joins the lamina to the stem or its branch. Sometimes the petiole is absent and then the leaf is said to be **sessile**.

Lamina is the expanded, green and conspicuous part of leaf which is specialised to perform photosynthesis. It is supported by veins and veinlets which contain vascular tissues for conduction of water, mineral salts and prepared food.

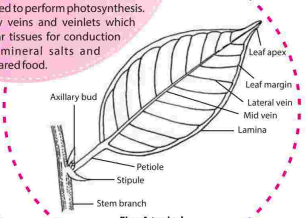


Fig.: A typical dicotyledonous leaf

Phyllotaxy

Phyllotaxy is the arrangement of leaves on the stem or its branches in such a way that all the leaves get proper exposure to sunlight. Phyllotaxy is of three main types –

(I) Spiral or alternate : A single leaf is borne at each node, *e.g., Hibiscus*, mango.

(ii) Opposite : A pair of leaves are borne at each node on opposite sides, *e.g., Quisqualis* (opposite superposed) and *Calotropis* (opposite decussate).

(iii) Whorled or verticillate : More than two leaves arise at each node, *e.g., Alstonia*.

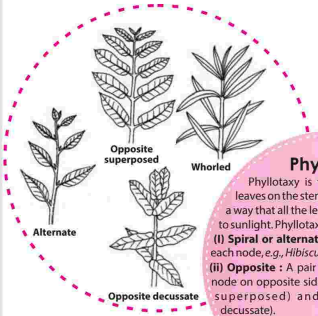



Fig.: Simple leaves

Simple and Compound leaves

A simple leaf is the one in which lamina is undivided or incised to any depth but not upto the midrib. In a compound leaf, lamina is completely broken up into distinct segments called leaflets which are separately articulated at the base. Compound leaves are of 2 types -

(a) Pinnate compound leaves : In these type of leaves, incision of lamina is directed towards the midrib which is known as **rachis.** Leaflets are arranged on both sides on the rachis or on its branches. These are of following types:

(i) Unipinnate : Leaflets are directly attached on the rachis, *e.g., Cassia fistula* (paripinnate), rose (imparipinnate).

(ii) Bipinnate : Rachis divides and gives rise to secondary axis on both sides on which leaflets are arranged, *e.g., Acacia.*

(iii) Tripinnate : Secondary axis too, divides and gives rise to tertiary axis on which leaflets are attached, *e.g., Moringa.*

(iv) Decompound : Rachis divides more than three times and gives rise to small axis on which leaflets are arranged, *e.g.,* carrot.

(b) Palmate compound leaves : In these type of leaves, incision of leaf is directed towards the petiole due to which all leaflets seem to be articulated on the upper end of petiole. It does not have any rachis. Depending on the number of leaflets present, a palmate compound leaf is called **unifoliate** (*e.g., Citrus*), **bifoliate** (*e.g., Balanites*), **trifoliate** (*e.g., Trifolium*), **quadrifoliate** (*e.g., Paris quadrifoliata*), multifoliate (*e.g., Bombax*).

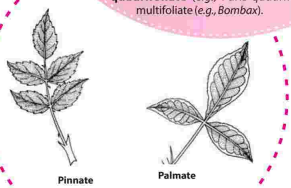
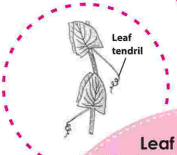


Fig.: Compound leaves



Leaf modifications

(i) Leaf tendrils : Leaves are modified into slender, wiry often closely, coiled structures, known as tendrils, which help in climbing. These may be whole leaf tendrils (*e.g., Lathyrus aphaca*), leaflet tendrils (*e.g., Pisum sativum*), petiolar tendrils (*e.g., Nepenthes*), leaf tip tendrils (*e.g., Gloriosa*), Stipular tendrils (*e.g., Smilax*), etc.

(ii) Leaf spines : These protect the plants from grazing animals and excessive transpiration *e.g., Solanum surattense.*

(iii) Leaflet hooks : The terminal leaflets of compound leaves become transformed into stiff claw-like and curved hooks. These help the plant in climbing, *e.g., Doxantha unguis-cati.*

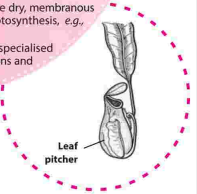
(iv) Phyllodes : These are the flattened petioles or parts of the rachis which perform the function of photosynthesis, *e.g., Acacia* species. These help to reduce transpiration in xerophytic plants.

(v) Insect catching leaves : Leaves are modified to form pitchers (*e.g., Nepenthes*), bladders (*e.g., Utricularia*) etc. to trap and digest insects.

(vi) Succulent leaves : These are fleshy leaves that store food material, *e.g., Aloe, Agave* etc.

(vii) Scale leaves (or **cataphylls**) **:** These are dry, membranous leaves which do not take part in photosynthesis, *e.g., Casuarina.*

(viii) Floral leaves : These are specialised leaves *i.e.,* sepals, petals, stamens and carpels.



Venation

Venation is the arrangement of veins and veinlets on the lamina of a leaf. Venation is of 3 main types - reticulate (veins form a network), parallel (veins run parallel) and furcate (veins branch dichotomously, *e.g., Circeaster*).

Reticulate venation is found in most dicots. Pinnate (or unicostate) reticulate venation occurs in *Ficus religiosa*. Palmate (or multicostate) reticulate venation occurs in *Zizyphus* (convergent), and *Luffa* (divergent).

Parallel venation occurs in most monocots. Pinnate (or unicostate) parallel venation occurs in banana. Palmate (or multicostate) parallel venation occurs in bamboo (convergent) and *Livistonia* (divergent).

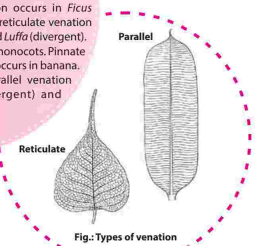


Fig.: Types of venation

Functions of the leaves

Primary functions: Photosynthesis, gaseous exchange, transpiration, protection of buds and conduction through veins.

Secondary functions : Storage *e.g.,* succulent leaves of *Aloe, Agave* etc.; protection *e.g.,* spiny leaves of *Barberry, Opuntia* etc.; support *e.g.,* leaflet hooks in *Doxantha*; nitrogen nutrition *e.g.,* leaf pitchers of *Nepenthes*; reproduction *e.g.,* leaves of *Bryophyllum* help in vegetative propagation; floral leaves help in sexual reproduction.

CONCEPT MAP

INFLORESCENCE

Inflorescence is the arrangement and distribution of flowers on the shoot system of a plant. The axis of the inflorescence is called peduncle, whereas the stalk of individual flower is called pedicel. A flattened peduncle is known as receptacle. Inflorescence is of five types- solitary, racemose, cymose, mixed and special.

Solitary

Flowers occur singly or are separated from other flowers of the same plant by vegetative regions.

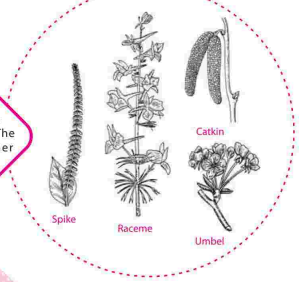
Solitary terminal
Single flower occurs on the terminal part of a branch, *e.g.*, poppy.

Solitary axillary
Single flower occurs in the axil of a leaf, *e.g.*, *Petunia*, China rose.

Racemose

It is an indeterminate inflorescence which shows indefinite growth. The arrangement of flowers is either **acropetal** (vertical orientation of axis) or **centripetal** (horizontal orientation of axis).

Compound racemose
Compound racemose inflorescence is an indefinite or indeterminate inflorescence in which the peduncle is **branched** repeatedly once or twice in a racemose fashion. It is of following types–
(a) **Compound raceme or panicle,** *e.g.*, goldmohur, *Cassia fistula, Yucca.*
(b) **Compound spike or spike of spikelets,** *e.g.*, wheat.
(c) **Compound spadix,** *e.g.*, coconut, date, banana.
(d) **Compound corymb,** *e.g.*, *Pyrus*, cauliflower.
(e) **Compound umbel,** *e.g.*, *Daucus carota*, fennel, *Coriandrum sativum.*
(f) **Compound capitulum,** *e.g.*, *Echinops.*



Simple racemose
Simple racemose inflorescence is an indefinite inflorescence in which the peduncle is **unbranched.**

Raceme
Peduncle is elongated having pedicellate flowers in an acropetal fashion, *e.g.*, *Lupinus, Raphanus, Linaria.*

Spike
An elongated peduncle bears sessile flowers in an acropetal fashion, *e.g.*, *Achyranthes, Callistemon, Adhatoda vasica.*

Spikelet
Spikelets are small and few flowered spikes which are surrounded at the base by two scales or glumes, *e.g.*, rice, bamboo, oat, etc.

Catkin
Pendulous spike which bears naked pistillate or staminate flowers, **(but not both)** *e.g.*, mulberry, poplar, *Salix, Quercus.*

Spadix
Spike with fleshy peduncle and having both male and female flowers. It is surrounded by a large green or coloured bract called **spathe,** *e.g.*, palm, *Colocasia, Musa.*

With long peduncle

With short peduncle

Umbel
All the pedicellate flowers arise from a single point in a centripetal fashion. The peduncle is very much reduced, *e.g.*, *Hydrocotyle, Prunus.*

Corymb
The main axis is comparatively short, and the lower flowers have much longer pedicels than the upper ones so that all the flowers are brought more or less to the same level, *e.g.*, *Iberis amara* .

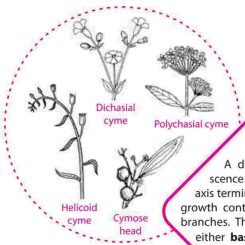
Corymbose raceme
The young flowers appear to be arranged like a corymb but in mature state the longer pedicels of the lower flowers do not bring them to the level of upper ones, *e.g.*, mustard.

With flattened peduncle

Capitulum
The flattened receptacle bears numerous sessile and small florets **(ray florets and disc florets)** in a centripetal manner, *e.g.*, *Zinnia*, Sunflower, *Cosmos.*

Cymose

A determinate inflorescence in which the tip of main axis terminates in a flower and further growth continues by one or more lateral branches. The arrange-ment of flowers is either **basipetal** (vertical orientation of axis) or **centrifugal** (horizontal orientation of axis).



Cymose head
Sessile or subsessile flowers are borne centrifugally around a receptacle, *e.g.*, *Albizzia, Anthocephalus cadamba, Acacia.*

Scapigerous Head
The leafless flowering axis known as **scape** bears clusters of flowers that form a head which is covered by **spaths**, *e.g.*, *Allium cepa.*

Biparous or Dichasial cyme
A terminal flower is subtended by two lateral branches which also end in flowers. The process is repeated. Inflorescence axis is multipodial, *e.g.*, *Spergula, Stellaria media, Clerodendrum.*

Multiparous or Polychasial cyme
More than two lateral branches continue the growth of inflorescence when the parent axis ends in a flower, *e.g.*, *Hamelia, Calotropis, Asclepias.*

Uniparous or Monochasial cyme
A single lateral branch arises from the peduncle of old flower which terminates in a flower. The lateral branch also terminates in a flower. It is of two types:
(a) **Helicoid cyme –** All the flowers are borne on the same side forming a sort of helix, *e.g.*, *Drosera, Begonia, Myosotis.*
(b) **Scorpioid cyme** - Flowers are alternately borne on both the sides, *e.g.*, *Tecoma, Ranunculus, Heliotropium.*

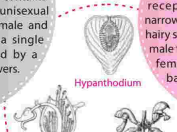
Mixed

Two or more types of inflorescences get mixed up to form a mixed inflorescences. It is of following types:
(a) **Panicle of spikelets,** *e.g.*, oat, rice.
(b) **Corymb of capitula,** *e.g.*, *Ageratum conyzoides.*
(c) **Umbel of capitula, raceme of capitula.**
(d) **Thyrsus,** *e.g.*, grapevine.

Special

Cyathium
The inflorescence looks like a flower. The bracts or the involucre become fused to form a cup shaped structure. The inflorescence contains pedicellate, achlamydeous, unisexual flowers of both the types, male and female. The cup encloses a single female flower surrounded by a large number of male flowers. *E.g., Euphorbia pulcherrima.*

Hypanthodium
It has a flask-shaped fleshy receptacle which possesses a narrow apical opening guarded by hairy structure. The receptacle bears male flowers towards the pore and female flowers towards the base. *E.g., Ficus religiosa, Ficus carica.*



Verticillaster
Two dichasial cyme inflore-scences develop from axil of opposite leaves. They together form a false whorl around the node, *e.g.*, *Ocimum, Leucus.*

CONCEPT MAP

MORPHOLOGY OF FRUITS AND SEEDS

A true fruit (or eucarp) is a ripened ovary. It consists of a thin or thick pericarp formed from the wall of ovary and seeds formed from the ovules. A fruit in which other floral parts (*e.g.*, thalamus, base of sepals, petals, etc.), participate in its formation is called **false fruit (or pseudocarp)** *e.g.*, apple and pear. The seeds within the fruits have reserve food for nourishing the young seedlings till they become nutritionally independent.

• Some fruits are formed without fertilisation *i.e.*, seedless fruits. They are called as **parthenocarps** (*e.g.*, banana). Fruits are classified into three main categories – **simple** fruits, **aggregate** fruits and **composite** fruits.

Simple fruits

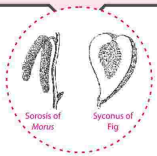
Simple fruits develop from monocarpellary ovary or multicarpellary syncarpous ovary. Simple fruits may be **dry** (pericarp is undifferentiated) or **succulent** (pericarp is differentiated into epicarp, mesocarp and endocarp).

Composite fruits

A composite or multiple fruit develops from the whole inflorescence. It is of two main types: sorosis and syconus.

Sorosis : These fruits develop from spike, spadix or catkin inflorescence. Sorosis of pineapple develops from an intercalary spike of sterile flowers with persistent bracts. Sorosis of mulberry develops from a female catkin.

Syconus : It develops from hypanthodium inflorescence. Receptacle becomes fleshy and edible, many achenes develop from pistillate flowers, *e.g., Ficus carica*.



Aggregate fruits

Aggregate fruits are the groups of fruitlets which develop from the multicarpellary, apocarpous ovaries. The individual carpel or pistil develops into a fruitlet and these fruitlets occur as a clustered unit on a single receptacle, which is referred to as an aggregate fruit or etaerio, *e.g.*, etaerio of achenes (*Ranunculus*, lotus), etaerio of follicles (*Calotropis*), etaerio of berries (Custard apple), etaerio of drupes (*e.g., Rubus idaeus*), etc.

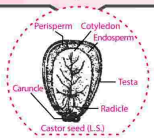
Dry fruits

Dry fruits are of three types – **Achenial** (single seeded, indehiscent), **capsular** (many seeded, dehiscent) and **schizocarpic** (many seeded, after ripening divide into single seeded segments).

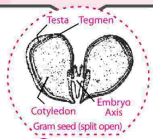
Seed

Seed is a ripened ovule which contains an embryo, adequate reserve food and a covering for protection against mechanical injury. A seed may have 1 or 2 coverings called **seed coats**. Outer is **testa** and inner is called **tegmen**. Seeds can be endospermic and non-endospermic.

(i) **Endospermic** or **albuminous seeds:** Endosperm is present and food reserve remains in endosperm, *e.g.*, most monocots and some dicots (*Ricinus communis*).



(ii) **Non-endospermic** or **exalbuminous seeds :** The endosperm is consumed during seed development and the food is stored in cotyledons, *e.g.*, majority of dicot seeds (*Cicer arietinum*) and in some monocot seeds.



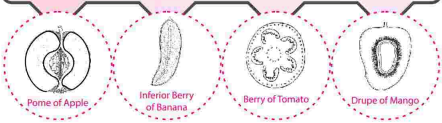
Succulent fruits

Succulent fruits can be divided into three main types: berry, drupe and pome.

(i) **Berry :** In superior or true berry (derived from superior ovary) usually all the three layers of fleshy pericarp are edible, *e.g.*, grape, tomato. In inferior or false berry (derived from inferior ovary) epicarp is fused with thalamus to form exocarp, *e.g.*, banana (parthenocarpic), guava. There are some special berries also such as **balausta** (*e.g.*, pomegranate), **pepo** (*e.g.*, cucumber), and **hesperidium** (*e.g.*, orange).

(ii) **Drupe (or stone fruit) :** In this fruit, epicarp forms the rind, mesocarp is fleshy and endocarp is hard and stony, *e.g.*, almond, mango, *Zizyphus*, etc.

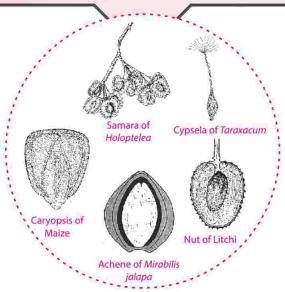
(iii) **Pome :** It is a false fruit that develops from the fleshy thalamus of multicarpellary, syncarpous, inferior ovary, *e.g.*, apple, pear, etc.



Achenial fruits (Indehiscent fruit)

Achenial fruits are of five types :

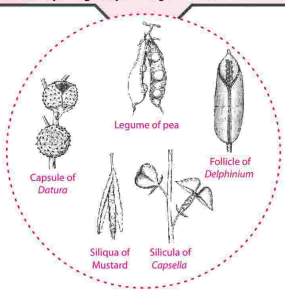
(i) **Achene :** It develops from monocarpellary, superior, unilocular and unioveled ovary, pericarp is free from seed except at one point, *e.g.*, *Mirabilis jalapa*. (ii) **Caryopsis (or Grain) :** It develops from monocarpellary, superior, unilocular ovary. Pericarp is completely fused with the testa, *e.g.*, members of family Poaceae. (iii) **Cypsela :** It develops from bicarpellary, syncarpous, inferior and unilocular ovary. Pappus may be present for dispersal, *e.g., Taraxacum*. (iv) **Nut:** Pericarp becomes hard, woody or leathery. Fruit may develop from monocarpellary, superior ovary (*e.g.*, cashew nut); tricarpellary, syncarpous, trilocular ovary (*e.g.*, litchi), etc. (v) **Samara :** Pericarp becomes flat like wings and thus help in wind dispersal *e.g., Holoptelea*.



Capsular fruits (Dehiscent fruit)

Capsular fruits are of five types:

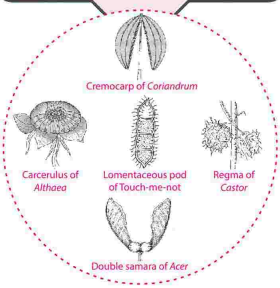
(i) **Legume (or pod) :** The fruit develops from superior, monocarpellary, unilocular ovary with marginal placentation. It dehisces by both dorsal and ventral sutures, *e.g.*, members of family Leguminosae. (ii) **Follicle :** The fruit dehisces by only one suture, *e.g., Delphinium*. (iii) **Siliqua :** It develops from a bicarpellary, superior ovary with parietal placentation and a false septum called replum. It dehisces by two valves, *e.g.*, members of family Brassicaceae. (iv) **Silicula :** It is a shortened and flattened siliqua, *e.g., Capsella bursa-pastoris*. (v) **Capsule:** According to the mode of dehiscence, capsule may be **porocidal capsule** (*e.g., Papaver*), **denticidal capsule** (*e.g.*, Pink), **pyxidium** (*e.g., Portulaca*), **loculicidal capsule** (*e.g., Gossypium*), **septicidal capsule** (*e.g., Viola*), **septifragal capsule** (*e.g., Datura*), etc.



Schizocarpic fruits (Splitting fruits)

Schizocarpic fruits are of five types :

(i) **Cremocarp :** It develops from a bicarpellary, syncarpous, bilocular, inferior ovary. On maturity, the fruit splits into two mericarps, each with one seed, *e.g.*, members of family Apiaceae. (ii) **Lomentum :** The fruit is a modification of legume, which is constricted in between the seeds, *e.g., Mimosa, Acacia*, etc. (iii) **Carcerulus :** At maturity, the fruit breaks up into single seeded indehiscent mericarps, *e.g., Althaea*. (iv) **Compound samara :** At maturity, the fruit splits up into single seeded winged mericarps, *e.g., Acer*. (v) **Regma :** It develops from multicarpellary pistil and on maturity, splits into as many cocci as the number of carpels, *e.g., Geranium*.



CONCEPT MAP

FLORAL MORPHOLOGY

A flower is a highly condensed and modified shoot. It contains reproductive organs of the flowering plants, which develop fruits and seeds. There are four types of floral organs *viz.* **sepals, petals, stamens and carpel or pistil.** A flower having all the four types of floral organs is known as **complete flower** *e.g.,* cotton. If one or more of the floral organs are absent it is called **incomplete flower** *e.g.,* cucurbits. A flower having both the essential organs *i.e.,* stamens and carpels is called **hermaphrodite** or **bisexual flower**, *e.g.,* China rose, whereas a flower having only one of the two essential organs is known as **unisexual flower** *e.g.,* mulberry. Flowers having only stamens are called **staminate** flowers and those having only carpels are called **pistillate** flowers. On the basis of symmetry flower can be **actinomorphic** (two equal halves in any plane), **zygomorphic** (two equal halves in one plane), or **asymmetrical**.

GYNOECIUM

- Central, female reproductive part which develops from thalamus and consists of **carpels (megasporophylls).**
- Each carpel consist of– **stigma** (the tip which receives pollen), **style** (elongated structure connecting stigma and ovary), **ovary** (lower swollen part containing ovules).
- On the basis of number of carpels present, it can be **moncarpellary** (one carpel only) or **multicarpellary** (many carpels) which can be **apocarpous** (carpels free *e.g., Ranunculus*) or **syncarpous** (carpels fused *e.g., Petunia*).
- On the basis of number of locules (chamber) present in the ovary, it can be **unilocular** (pea), **bilocular** (mustard), **trilocular** (*Asparagus*), **tetralocular** (*Ocimum*), **pentalocular** (China rose) or **multilocular** (*Althaea*).

- The stamens may be **equal** or **unequal** in length. When there is two long and two short stamens, the condition is called **didynamous**, *e.g., Ocimum*. When out of six stamens, four are longer in inner whorls and two in outer whorl are shorter, the condition is called **tetradynamous,** *e.g.,* mustard.
- **Dehiscence of anthers** to expose the pollen grains can be **longitudinal** (long slits appear lengthwise *e.g.,* mustard), **transverse** (breadthwise slits, *e.g., Malva*), **porous** (pores appear at the tip *e.g., Solanum* or base *e.g., Cassia*), **valvular** (split at several places by lifting of surface layers. *e.g., Barberry*), **irregular** (*e.g., Najas*).
- Longitudinal dehiscence may be **laterorse** (slits on sides), **introrse** (slits towards the inner side or centre of the flower), **extrorse** (slits lie towards the outer side of flower).

ANDROECIUM

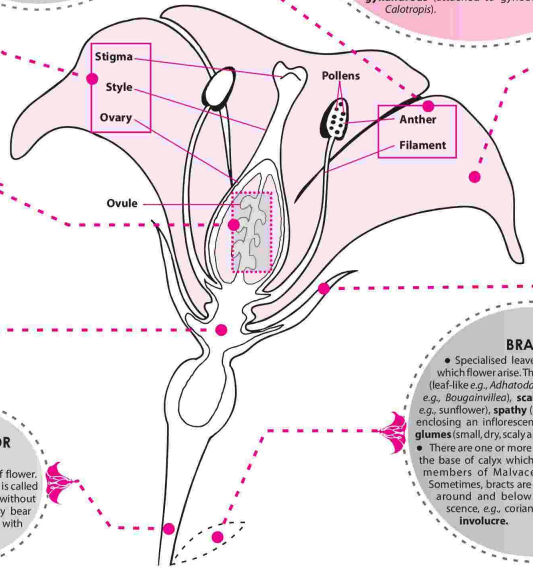
- Third and male whorl of the flower made up of **stamens (microsporophylls)** which consist of **filament** (lower stalk-like part which may be absent in some), **anther** (upper swollen part usually having two lobes or theca *i.e.,* **bithecous** or in some **monothecous,** *e.g., Althaea*) and **connective** (sterile band which connects two anther lobes). In *Salvia,* connective forms a long curved structure, its one end has a fertile anther lobe and other has a sterile anther lobe. Stamens may be shorter than other whorls (**inserted**) or may protrude out of the flower (**exserted**).
- On the basis of attachment to the filament, anthers can be **adnate** (filament runs along the back of the anther or becomes continuous with the connective, *e.g., Ranunculus*), **basifixed** (filament fixed at anther its base, *e.g., Datura*), **dorsifixed** (filament attached to back and anther immobile, *e.g., Passiflora*), **versatile** (filament attached to back and the anther can swing freely, *e.g.,* grasses).
- The cohesion between the stamens may be **monadelphous** (all the filaments united into a single bundle, anthers free, *e.g.,* China rose), **diadelphous** (filaments united in two bundles, anthers free, *e.g.,* pea), **polyadelphous** (filaments united into more than two bundles, anthers free, *e.g.,* castor), **syngenesious** (anthers united into a bundle, filaments free, *e.g.,* sunflower), **synandrous** (anthers as well as filaments united throughout the length, *e.g., Colocasia*). The free stamens are called **polyandrous.**
- On the basis of adhesion of stamens to flower, it can be **epiphyllous** (attached to perianth, *e.g., Asphodelus*), **epipetalous** (attached to petals, *e.g., Datura*), **gynandrous** (attached to gynoecium, *e.g., Calotropis*).

COROLLA

- Second whorl inner to calyx made up of petals which protects the inner whorls and attracts insects for pollination. Corolla may be **polypetalous** (petals free) or **gamopetalous** (petals fused).
- **Polypetalous corolla** may be **cruciform** (four clawed or unguiculate petals arranged cross wise *e.g.,* mustard), **caryophyllaceous** (five unguiculate or clawed petals with limbs placed at right angles, *e.g., Dianthus*), **rosaceous** (five or more sessile or shortly clawed petals with limbs spread regularly outwards, *e.g.,* rose), **campanulate or bell-shaped** (*e.g., Physalis*), **papilionaceous** (five unequal or irregular petals *viz.* 1 standard or vexillum – posterior largest–, 2 wings or alae –lateral, smaller– and 2 anterior petals fused together to form keel or carina).
- **Gamopetalous corolla** may be **campanulate** (bell-shaped or inverted cup shaped *e.g., Campanula*), **urceolate** (urn-shaped *e.g., Bryophyllum*), **tubular** (tube-like or cyclindrical *e.g.,* disc floret of sunflower), **infundibuliform** (funnel shaped *e.g., Petunia*), **rotate** (corolla with short tube having limbs placed transversely like a saucer or the spokes of a wheel, *e.g., Solanum nigrum*), **salver shaped or hypocrateriform** (tubular corolla with spreading lobes, *e.g., Clerodendrum*), **bilabiate** (bilipped corolla with gaping, wide open mouth, *e.g., Ocimum*), **personate** (bilipped corolla with closed lips, *e.g., Antirrhinum*), **ligulate or strap-shaped** (short and narrow tube-like corolla with upper part flattened like a strap, *e.g.,* ray floret of sunflower), **spurred** (one or more petals drawn out like a beak or spur, *e.g., Larkspur*).

PLACENTATION

- Arrangement of placenta (which bear ovules) on the ovary wall which can be :
  - (i) **Marginal :** One or two longitudinal alternate rows of ovules along the ventral suture in unilocular ovary, *e.g.,* pea, *Cassia* etc.
  - (ii) **Parietal :** Ovules on walls of bi–multicarpellary but unilocular ovary *e.g., Argemone.*
  - (iii) **Axile :** In multicarpellary, syncarpous, multilocular gynoecium; margins fuse at the centre of the ovary to form an axis which bears ovule *e.g., Solanum.*
  - (iv) **Free central :** Unilocular ovary with ovules borne on central axis *e.g., Dianthus.*
  - (v) **Basal :** Ovary unilocular with a single ovule at its base, *e.g.,* sunflower.
  - (vi) **Superficial :** Multicarpellary, syncarpous gynoecium bears a large number of ovules that are borne on the walls of loculi without specific order, *e.g., Nymphaea.*



AESTIVATION

- Arrangement of petals (or sepals) in a flower bud with respect to members of the same whorls which can be **open** (margins of adjacent petals sufficiently apart from each other), **valvate** (margins of the adjacent petals lie close, without overlapping, *e.g.,* mustard), **twisted or contorted** (one margin of a petal overlaps the margin of an adjacent petal (external) and the other margin is overlapped (internal) by the margin of adjacent petal, *e.g.,* China rose), **imbricate** (one petal external, one internal; and of the remaining three petals one margin is overlapped, other overlapping, *e.g., Cassia*), **quincuncial** (special type of imbricate aestivation in which two petals external, two internal and in one petal one margin is overlapped, one is overlapping, *e.g.,* calyx of *Cucurbita maxima*), **vexillary** (posterior petal overlapping the two lateral petals, the latter overlapping the two anterior petals, *e.g.,* pea).

THALAMUS (Torus/Receptacle)

- Broadened or swollen part of the flower which lies at the tip of the pedicel and bears floral organs.
- In most flowers the thalamus is condensed but in some, one or more internodes elongate *viz.* **anthophore** (internode between calyx and corolla *e.g., Dianthus*), **androphore or gonophore** (internode between corolla and androecium, *e.g., Passiflora*), **gynophore** (internode between androecium and gynoecium, *e.g., Capparis*), **gynandrophore or androgynophore** (both androphore and gynophore present, *e.g., Gynandropsis pentaphylla*), **carpophore** (the thalamus in between the two carpels elongates and after bifurcation protrudes out of the two carpels, *e.g., Coriandrum*).
- On the basis of relative position of floral organs on thalamus flower may be **epigynous** (ovary inferior, placed below other whorls, *e.g.,* guava), **hypogynous** (ovary superior, *e.g.,* China rose), or **perigynous** (ovary half superior or half inferior and thalamus may be disc *e.g.,* pea, cup *e.g., Prunus* or flask *e.g.,* rose shaped).

BRACTS

- Specialised leaves from the axil of which flower arise. They can be **foliaceous** (leaf-like *e.g., Adhatoda*), **petaloid** (like petals, *e.g., Bougainvillea*), **scaly** (membranous, small *e.g.,* sunflower), **spathy** (large, boat-shaped bract enclosing an inflorescence, *e.g.,* banana, maize), **glumes** (small, dry, scaly as in spikelet of Poaceae).
- There are one or more whorls of bracts found at the base of calyx which form **epicalyx** in most members of Malvaceae, *e.g.,* China rose. Sometimes, bracts are in one or more whorls around and below the entire inflorescence, *e.g.,* coriander and are called **involucre.**

CALYX

- Outermost whorl made up of sepals which are usually green but sometimes coloured (*i.e.,* **petalloid**). They protect the inner whorls and carry out photosynthesis when green.
- The sepals may be free (**polysepalous**) or fused (**gamosepalous**). They can be **caducous** (fall just at the time of opening of bud, *e.g.,* poppy), **deciduous** (attached till the flower withers, *e.g.,* mustard), **persistent** (remain attached to the fruit, *e.g.,* tomato).
- Sepals can be modified to form **pappus** (hairy structure which helps in dispersal *e.g.,* sunflower), **leafy petalloid** (large leaf like coloured structure, *e.g., Mussaenda*), **spinous** (persistent and modified into spines, *e.g., Trapa*), **spurred** (drawn out into beak or spur, *e.g., Larkspur*), **hooded** (modified into a hood, covering the whole flower, *e.g., Aconitum*) or **bilabiate** (two-lipped, *e.g., Salvia*).

PEDICEL OR STALK

- Lower internode of flower. A flower with pedicel is called **pedicellate** and one without it, is **sessile.** It may bear **bracteoles** along with the bracts.

CONCEPT MAP

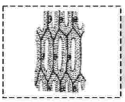
SIMPLE PERMANENT TISSUES

Tissues can be defined as a group of cells having a common origin that interact with one another to perform a similar function. Plants are formed of two types of tissues, on the basis of tissues and on the basis of ability of cells to divide, *i.e.*, **Meristematic** (divide indefinitely) and **Permanent.** Permanent tissues are those plant tissues that have lost the capacity to divide and attain a permanent shape, size and function due to morphological, biochemical and physiological differentiation. Based on the composition, permanent tissues can be **simple** or **complex**.
Simple permanent tissues are made up of structurally similar cells that carry out the common function.

There are three types of simple permanent tissues

PARENCHYMA

- Most abundant and common tissue of plants.
- Composed of thin walled, isodiametric cells that may be oval, rounded or polygonal in outline.
- Cell wall is cellulosic and encloses a large central vacuole and a peripheral cytoplasm containing nucleus.
- Cells may be closely packed or have small intercellular spaces between them.
- Cells form symplasm or living continuum as they connect with the adjacent parenchyma cells by plasmodesmata.
- It is usually used for storage of food and provides turgidity to softer parts of plants.
- It may be variously modified to perform special functions.

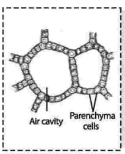


Prosenchyma

Fibre like elongated parenchyma with slightly thick walls.
Function: Provides rigidity and strength.

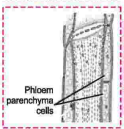
Idioblasts

The non-green, large sized parenchyma cells possessing inclusions or metabolic waste products like resins, tannins, crystals of calcium carbonate, calcium oxalate, etc.



Aerenchyma

The parenchyma in hydrophytes and some land plants get specialised to form network of parenchyma cells, enclosing large intercellular spaces filled with air *i.e.*, air cavities called as aerenchyma.
Function: Stores air or gases that helps in making aquatic plants light and buoyant.

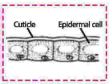


Phloem parenchyma

Thin walled, elongated parenchymatous cells having abundant plasmodesmata.
Function: Stores food, resins, mucilage, latex, etc., as well as help in lateral conduction of food.

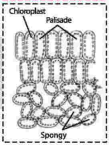
Cutinised parenchyma

The parenchymatous cells become cutinised to form a distinct protective covering or layer called **epidermis**.
Function: Checks excessive loss of water due to transpiration and protects inner soft parts.



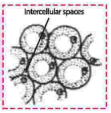
Chlorenchyma

Chloroplast containing parenchymatous cells. It is also called assimilatory parenchyma since it performs photosynthesis. It is differentiated into two types: palisade (columnar in shape) and spongy (round in shape).



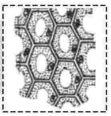
Storage parenchyma

Parenchyma sometimes get specialised by becoming enlarged and enclosing large vacuole. They are usually colourless.
Function: Stores food, water, mucilage or ergastic substances.



Xylem parenchyma

These are small and thick walled parenchymatous cells having simple pits.
Function: Helps in lateral conduction of water or sap and storage of food.



COLLENCHYMA

- Simple, living mechanical tissue, usually present in hypodermal regions of plant part or organs.
- Cells are conspicuous, elongated and are circular, oval or angular in transverse section.
- Each cell encloses a large central vacuole and a peripheral cytoplasm with chloroplasts often present.
- The cell wall have uneven pectocellulosic thickenings, a characteristic feature of collenchyma.

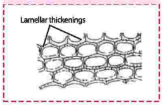
Functions:

- Provides both mechanical strength and elasticity to young dicot stem, petioles and leaves.
- Provides flexibility to organs and allow bending, *e.g.*, in *Cucurbita* stem and prevents tearing of leaves.
- Permits growth and elongation of organs.
- Stores food and performs photosynthesis when chloroplasts are present.

Depending upon thickening, the collenchyma is of three types:

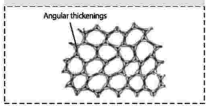
Lamellar collenchyma

- Cells are compactly arranged in rows.
- The cells have thickenings on tangential walls, *e.g.*, stem of sunflower.



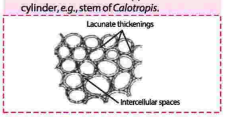
Angular collenchyma

- Most common type of collenchyma.
- Cells are irregularly arranged.
- Cell wall have thickening in the corners or angles and therefore intercellular spaces are absent, *e.g.*, stem of *Datura*, tomato.



Lacunar collenchyma

- Cells are irregularly arranged, hence intercellular spaces are present.
- Thickenings are present on cell wall around intercellular spaces, such thickenings are called lacunate thickenings.
- The thickened cell wall appears as a hollow cylinder, *e.g.*, stem of *Calotropis*.



SCLERENCHYMA

- Widely distributed, simple mechanical tissue.
- Comprises of dead and empty cells with highly thickened cell walls having little or no protoplasm.
- The lumen or cell cavity is narrow or highly reduced and sometimes obliterated (closed).
- The wall thickenings are made up of cellulose and lignin and may have few to numerous pits.

Sclerenchyma fibres

- Highly elongated, narrow, spindle shaped, thick walled cells with pointed or oblique end walls.
- Fibres occur in longitudinal bundles with the ends of adjacent fibres being interlocked to form a strengthening tissue.
- These are dead and empty at maturity with the exception in *Tamarix aphylla*, where fibres are living.

On the basis of length of cells, they may be of two types:

Libriform fibres
Long and narrow fibres with slightly lignified secondary walls, having simple pits.

Fibre tracheids
Comparatively shorter fibres with moderate secondary thickenings in the cell walls, having bordered pits.

Wood fibres

Fibres associated with secondary xylem tissues and are derived from vascular cambium. Also called xylary or intraxylary fibres.

Bast fibres or extraxylary fibres

Long fibres with lignified walls having simple or bordered pits. Found in cortex, pericycle and phloem.

Surface fibres

Arise from the surface of plant organs, *e.g.*, cotton fibres from testa of seeds, mesocarp fibres of coconut.

Types of Fibres

Sclereids

- Broader and shorter than fibres, ranging from isodiametric, polyhedral, spherical, oval, short or cylindrical cells.
- Highly thickened dead cells with very narrow cavities and may have branched or unbranched simple pits.
- Occur either singly or in groups and impart stiffness to regions, where they are present.

Types of Sclereids

Brachysclereids

Isodiametric, short and unbranched cells with ramiform pits. Abundantly present in soft parts like cortex, phloem, flesh of fruits, *e.g.*, guava, pear, apple, etc. Also called **stone cells.**

Osteosclereids

Bone shaped sclereids with rod like enlarged or lobed ends. Found in leaves and sub-epidermal covering of leguminous seeds, *e.g.*, *Phaseolus*

Macrosclereids

Slightly elongated and columnar rod shaped cells. Form epidermal covering of leguminous seeds such as pea and bean.

Filiform sclereids

Fibre like, sparingly branched sclereids. Found in leaves of *Olea*.

Astrosclereids

Star like, stellate sclereids having lobes. Found in leaves and petioles of aquatic plants, *e.g.*, *Nymphaea*.

CONCEPT MAP

ANATOMY OF DICOTS

Anatomy is the study of internal structures of various parts of a living organism. Anatomy of dicot plants deals with the internal structures of stem, root and leaves of plants.

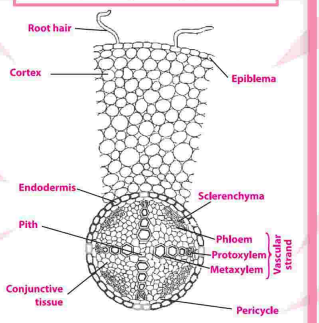
ANATOMY OF DICOT ROOT

- It is situated below epiblema and is made up of thin-walled parenchyma cells with intercellular spaces.
- Cortical cells store starch.

- Innermost layer of cortex is called **endodermis**. It is made up of single layer of barrel-shaped cells lacking intercellular spaces.
- Young endodermal cells possess **Casparian strips** (bands of thickening which run along their radial and tangential wall).
- Casparian strips prevent plasmolysis of endodermal cells and do not allow wall to wall movement of substances between cortex and pericycle.
- Endodermal cells opposite to protoxylem point lack Casparian strips and are called **passage cells**.

- It is found in the centre and is often reduced or absent in dicot root.
- If present, it consists of parenchyma cells without intercellular spaces.

- Xylem and phloem bundles are separated from each other by one or more layers of small thin-walled cells called conjunctive parenchyma.
- It becomes meristematic to form vascular cambium.



T.S. of dicot root

- It is the outermost layer of root.
- Made up of compactly arranged, thin-walled, parenchymatous cells.
- Distinct cuticle and stomata are absent.
- Some cells of epiblema give rise to thin-walled tubular outgrowths called **root hairs**. These absorb water and mineral salts from the soil.
- Due to presence of root hairs, the epiblema is also called **piliferous layer**.

- Vascular bundles are **radial**, *i.e.,* xylem and phloem are situated on different radii and **exarch**, *i.e.,* protoxylem away from the centre and metaxylem towards the centre.
- Roots may be **diarch** (2 xylem bundles), **triarch** (3 xylem bundles), **tetrach** (4 xylem bundles), **pentarch** (5 xylem bundles) or **hexarch** (6 xylem bundles).

- It is usually a single layered structure found below the endodermis and represents the outer boundary of stele.
- All lateral roots originate from pericycle.

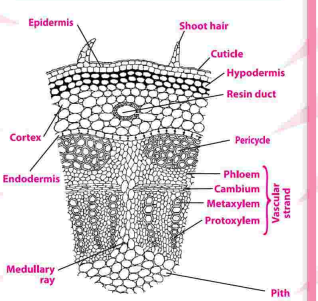
ANATOMY OF DICOT STEM

- It is the outermost layer of stem and is protective in function.
- Made up of compactly arranged, parenchymatous cells devoid of chloroplasts (except guard cells).
- The outer walls of epidermal cells are cuticularised.
- Stomata and multicellular hair are present in epidermis.

- Consists of thin-walled parenchymatous cells with inter-cellular spaces.
- Major function of cortex is food storage.

- It is the innermost boundary of cortex made up of compactly arranged barrel-shaped cells without Casparian strips.
- Endodermal cells of stem store starch grain and are often referred to as **starch sheath**.

- They are radial strips of parenchyma which are present between adjacent vascular bundles.
- They connect pith with pericycle and cortex.
- Ray cells are larger than cortical cells.



T.S. of dicot stem

- Hypodermis lies just below epidermis and consists of 3-5 layers of collenchymatous cells.
- The intercellular spaces are absent and corners of cells are thickened due to deposition of extra cellulose impregnated with pectic substances.
- These cells often possess chloroplasts.

- Pericycle is **heterogenous**, *i.e.,* made up of alternating bands of parenchymatous and sclerenchymatous cells.
- Sclerenchymatous cells are situated in between endodermis and phloem cells of vascular bundles whereas parenchymatous cells are present above the medullary rays.

- Vascular bundles are arranged in a ring and are **conjoint** (with both phloem and xylem), **collateral** (phloem and xylem on same radius) and **open** (with a strip of cambium between phloem and xylem). Xylem is situated towards the inner side of each vascular bundle whereas phloem lies towards the pericycle on the outer side of vascular bundle.
- Xylem is **endarch** (protoxylem towards the centre).

- It is extensively developed central portion of ground tissue, made up of large thin-walled polygonal parenchymatous cells with intercellular spaces.

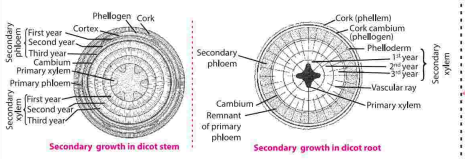
Secondary growth in dicots

Secondary growth in dicot stem

In a typical dicot stem the cambium is present in between the xylem and phloem. It is called **fascicular** or **intrafascicular** cambium. Along with this cambium, some medullary ray cells also become active forming **interfascicular** cambium. Interfascicular and intrafascicular cambia together form a ring of cambium. Cambial cells give rise to secondary phloem on the outer side and secondary xylem on the inner side. **Phellogen** or cork cambium arises from permanent living cells of hypodermis or outer cortex. It divides to give rise to phellem (cork) on the outerside and phelloderm (secondary cortex) on the inner side.

Secondary growth in dicot root

In dicot roots cambium develops at the time of secondary growth. First of all parenchyma cells interior to the phloem become meristematic, and strips of cambia are formed. Later, these strips divide tangentially again and again and produce secondary tissues. The cells of pericycle lying opposite to each protoxylem divide and form a few layers of cell. Thus, a wavy continuous cambium ring is produced which cuts-off secondary xylem internally at all places and secondary phloem at all places externally. Cork cambium arises as a result of the tangential division of the outer cells of pericycle. The activity of cork cambium is similar to that found in dicot stem so it produces cork cells on the outer side and parenchyma on the inner side.



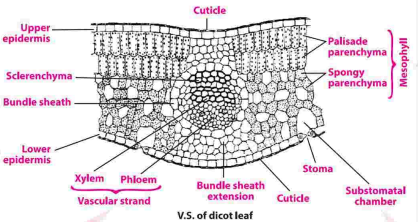
Secondary growth in dicot stem

Secondary growth in dicot root

ANATOMY OF DICOT LEAF

- Consists of a single layer of tightly packed rectangular barrel-shaped parenchymatous cells usually devoid of stomata and chloroplasts.
- Outer walls of epidermal cells are cuticularised.

- This is like upper epidermis but with stomata and chloroplasts (in guard cells only).
- Outer walls of cells are cuticularised.



V.S. of dicot leaf

- The tissue between upper and lower epidermis is called mesophyll.
- It is differentiated into 2 regions:

(i) **Palisade parenchyma:** It lies below upper epidermis and consists of 1-3 layers of vertically elongated closely placed, columnar or cylindrical cells. These cells have numerous chloroplasts and take part in photosynthesis.

(ii) **Spongy parenchyma:** It is found below palisade tissue. The cells are almost spherical and irregularly arranged with intercellular spaces. They also possess chloroplasts but fewer than present in palisade parenchyma and take part in photosynthesis.

- Vascular bundles are generally found at the boundary between the palisade and spongy regions.
- Vascular bundles are **conjoint** and **collateral.**
- Around each vascular bundle a sheath of parenchymatous cells called **bundle sheath** is present.
- The midrib contains a number of vascular bundles which are embedded in parenchymatous ground tissue.

- Substomatal chamber is present below the stomata which helps in exchange of gases and is also called **respiratory cavity**.

CONCEPT MAP

ANATOMY OF MONOCOTS

Monocots or monocotyledonous plants are those plants whose seeds contain only one cotyledon. Anatomy of monocots deals with the internal structures of root, stem and leaves.

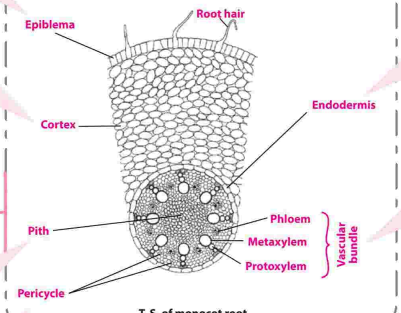
ANATOMY OF MONOCOT ROOT

- It is the outermost layer having thin walled, uncutinised colourless cells and are without intercellular spaces. It is characterised by the presence of unicellular hairs.
- It is also called **rhizodermis** (Piliferous Layer).
- Root hairs take part in absorption of water and mineral salts.

- Below the epiblema, cortex is present.
- It is very wide region of parenchymatous cells that encloses intercellular spaces for the exchange of gases.
- In older roots, the outer one (*e.g., Smilax)* or more layers (*e.g.,* maize) of the cortex become thick walled and suberised and constitute **exodermis**. (It is protective and to some extent absorptive in function).
- The function of cortex in a monocot root is
  (i) Conduction of water from the root hairs to the inner tissues.
  (ii) Production of protective exodermis in older roots.
  (iii) Storage of food.

- The centre of monocot root is occupied by pith.
- It consists of parenchymatous cells (thin or thick walled) which may be rounded or angular.
- Intercellular spaces are present amongst the pith cells.
- The function of pith cells is to store food.

- It is the outer boundary of vascular bundle below the endodermis.
- Pericycle is composed of thin-walled parenchymatous cells in the young root. But in many monocots, it becomes thick-walled in later stages.
- Pericycle may be uniseriate, (*e.g.,* maize) or multiseriate (*e.g., Smilax* and *Salix*).
- The pericycle does not form cambium (in monocots) but produces lateral roots only.



T. S. of monocot root

- There is not much distinction between a young and an old root of monocot plants due to the absence of secondary growth in the monocot roots.

- It is an inner boundary of the cortex and is usually single layered.
- It is made up of barrel-shaped cells which do not enclose intercellular spaces.
- Endodermal cells are characterised by the presence of **Casparian strips** (an internal strip of suberin and lignin) and get thickened.
- Some endodermal cells (opposite to protoxylem) remain unthickened and devoid of casparian strips and are called **passage cells** or transfusion cells.

Functions of endodermis are
(I) It functions as a mechanical protective layer.
(ii) Maintenance of the root pressure.
(iii) It regulates the flow of fluid both inwardly as well as outwardly by functioning as biological check post.

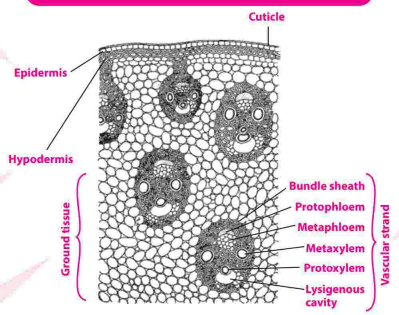
- Vascular bundle is in the form of several alternate and radial xylem and phloem bundles.
- The vascular bundles are embedded in a cylinder of sclerenchymatous conjunctive tissue (*e.g.,* maize).
- The vascular bundles are arranged in the form of ring around a central pith.
- The xylem bundles are *exarch i.e.,* protoxylem lies towards the outside while the metaxylem faces inwards.
- Xylem of monocot root is *polyarch i.e.,* presence of numerous xylem bundles.
- The xylem provides mechanical strength and helps in the conduction of water and mineral salts.
- Phloem bundles alternate with the xylem bundles. These two are separated from each other by means of narrow strip of **conjunctive tissue.**
- The cells of conjunctive tissue store food if parenchymatous and provide mechanical strength on becoming sclerified but they do not take part in formation of cambium.
- The function of phloem is conduction of organic food.

ANATOMY OF MONOCOT STEM

- It is the outermost layer of the stem composed of compactly arranged, transparent, elongated and rectangular barrel- shaped parenchyma cells.
- The outer wall of epidermal cells possess deposition of silica (provides stiffness) and cutin. The epidermal cells are cutinised which prevent the evaporation of water from the stem.
- Hairs are absent.
- Epidermis possess two dumb-bell shaped guard cells of pores called stomata (for gaseous exchange).

- It possess two to three layers of sclerenchyma below the epidermis.
- Intercellular spaces are absent in this tissue.
- Provides rigidity and mechanical strength to the plant and act as heat screen

- The entire mass of parenchymatous cells next to hypodermis form ground tissue.
- There is no differentiation between cortex, endodermis, pericycle and pith.
- The cells contain reserve food materials due to the presence of chlorenchymatous cells.
- In the peripheral ground tissue, the cells are smaller, polygonal and compactly arranged while towards the centre, they become loosely arranged, rounded and are bigger. Vascular bundles are embedded in this tissue.
- Abundant intercellular spaces are present.



T. S. of monocot stem

- A monocot stem lacks secondary growth. Therefore, it possess only the primary permanent tissues.
- The stem can be **solid** (*E.g.,* maize, *Asparagus*) or fistular (with central cavity, *e.g.,* grass).

- The vascular strand is in the form of **atactostele** (where a large number of vascular bundles lie scattered throughout the ground tissue).
- Each vascular bundle is surrounded by a sclerenchymatous bundle sheath. This sheath is extensively developed at the upper and lower faces of vascular bundles.
- Vascular bundles are conjoint, collateral but closed and endarch in condition.
- The vascular bundles are almost oval in outline and are made up of xylem and phloem only.

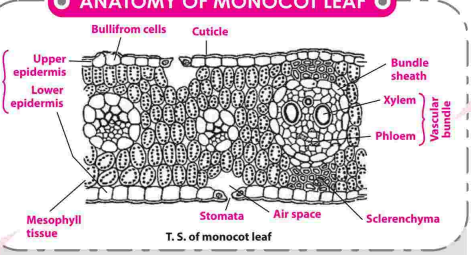
(a) Phloem : It is found above the xylem and made of sieve tubes and companion cells.
- Phloem parenchyma is absent.
- Phloem can be distinguished into an outer protophloem and inner metaphloem.
- The protophloem gets crushed in the later stages.

(b) Xylem : It consists of vessels, tracheids and xylem parenchyma.
- The metaxylem and protoxylem elements are arranged in the form of letter 'Y'.
- The divergent ends of 'Y' are occupied by two big, oval metaxylem vessels with pitted thickenings.
- In between, there are small tracheids.
- The protoxylem is positioned radially towards the centre (lower arm of Y), consisting of two smaller vessels with annular and spiral thickenings.
- In a completely mature vascular bundle, a schizolysigenous cavity is formed by disintegration of protoxylem and these cavities are filled with water.

ANATOMY OF MONOCOT LEAF

- There is a upper and lower layer of epidermis, covering both the surfaces respectively.
- Both the layers are composed of a single layer of cells and possess stomata hence, called **amphistomatic**.
- Some cells in the upper epidermis become large and are called **bulliform** cells or **motor cells** (helps in rolling of leaves during drought) and occur in group.
- The epidermal cells are cuticularised, therefore, protect from microbial attack and drought, besides regulating transpiration.

- The mesophyll is not differentiated into **palisade** and **spongy parenchyma**.
- Its cells are chlorenchymatous, large isodiametric, enclose small intercellular spaces and are irregularly arranged.



T. S. of monocot leaf

- It is also called **Isobilateral leaf** and are generally vertical where both the surfaces are equally green.
- The thick cuticle, sclerenchyma patches and motor cells are the **xerophytic** features of the leaf.

- There are a number of large and small vascular bundles.
- Each bundle is surrounded by a layer of thin-walled cells called bundle sheath.
- The cells of bundle sheath contains starch.
- The large bundles have prominent sclerenchyma patches on both the upper and lower sides extending from vascular bundle to epidermis.
- The larger bundles have a distinct phloem towards the lower epidermis and xylem towards upper epidermis.
- The xylem consists of two pitted metaxylem vessels (oval in shape). In between them, tracheids are also present.
- Protoxylem is represented by a lysigenous cavity, which faces the upper epidermis **(adaxial side)**.
- The smaller bundles are surrounded by individual sheaths and contain phloem and xylem.
- Phloem is present towards lower epidermis **(abaxial side)**.
- The vascular bundles are conjoint, collateral and closed.

CONCEPT MAP

COCKROACH

Cockroaches are brown or black bodied animals included in **Class Insecta** of **Phylum Arthropoda**. They are nocturnal omnivores, that live in damp places and the most common insects usually found in the houses. They are serious pests and vectors of diseases. The common species is ***Periplaneta americana***.

MORPHOLOGY

Body is narrow, elongated, bilaterally symmetrical and dorso-ventrally flattened.
Body is covered by chitinous brown coloured **exoskeleton** that provides support and rigidity and has hardened plates called **sclerites** formed by cuticle (tergites dorsally and sternites ventrally). They are joined to each other by **articular membrane** (arthrodial membrane) which allows movement of body and appendages.
Adults are 24-35 mm long with their body segmented into three regions – **head, thorax** and **abdomen.**
Head is triangular, formed by fusion of 6 segments and shows great mobility due to flexible neck. Head capsule bears a pair of **compound eyes** and a **pair of antennae** which have **sensory receptors.**
Mouthparts are of chewing and biting type and consists of: **labrum , labium ,** a pair each of **maxillae** and **mandibles** and a **hypopharynx.** A broad rectangular **clypeus** forms lower part of face.
Thorax consists of 3 parts – **prothorax** (neck), **mesothorax** and **metathorax.**
Each thoracic segment bears a pair of walking legs. Each leg consists of a series of segments or **podomeres.**
There are two pairs of wings arising from meso and metathorax: **forewings** and **hindwings.**
Abdomen is 10 segmented and contains a pair of **anal cerci,** in both females and males. The differences between male and female abdomen are: Abdomen of females is broader than males and males bear anal styles in 9th sternum which are absent in females.

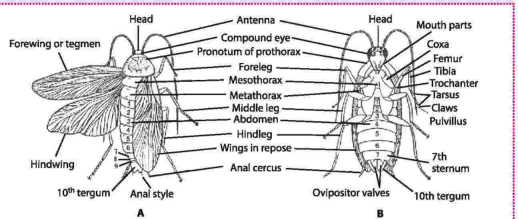
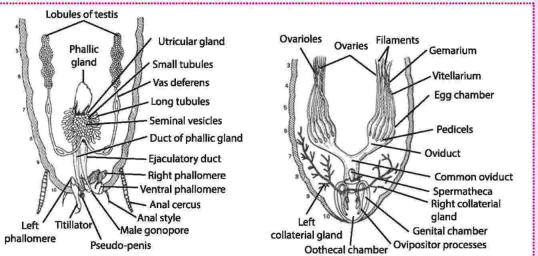


Fig.: *Periplaneta* external features. A-Male in dorsal view, B-Female in ventral view



ANATOMY

Digestive System

- Alimentary canal is divided into 3 regions: foregut, midgut and hindgut.
- **Foregut** and **hindgut** are ectodermal and lined by cuticle whereas, midgut is endodermal and lacks cuticle.
- **Foregut :** Mouth opens into pharynx and leads to narrow oesophagus which in turn opens into a sac like **crop** used for storing food. This is followed by **gizzard** (proventriculus) which has 6 highly chitinous plates called teeth, used for grinding food particles.
- **Midgut :** It is short and narrow. At the junction of foregut and midgut, 6-8 blind tubules called **hepatic caecae** are present which secrete digestive juice. At the junction of midgut and hindgut, thin filamentous 100-150 **Malpighian tubules** are present which remove excretory products from haemolymph.
- **Hindgut :** It is differentiated into ileum, colon and rectum. Rectum has 6 **rectal glands.** It opens out through anus. Hindgut is more pervious to water than foregut.

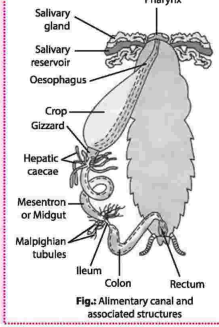


Fig.: Alimentary canal and associated structures

Circulatory System

- Heart of cockroach is **neurogenic.**
- It is enclosed by dorsal pericardial sinus and consists of elongated muscular tube differentiated into 13-funnel shaped chambers with **ostia** on either side. These allow flow of blood from pericardial sinus into heart only and not reverse.
- Blood vascular system is of open type and vessels open into **haemocoel.**
- Visceral organs located in haemocoel are bathed in blood **(haemolymph)** which consists of colourless plasma and haemocytes. Haemolymph is devoid of respiratory pigment and hence does not assist in respiration but in transfer of food material and metabolic wastes.

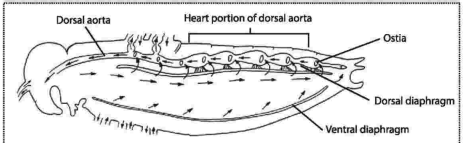


Fig.: Open type blood vascular system

Respiratory System

- It consists of network of **tracheae** that opens through **10 pairs of spiracles** present on lateral side of body guarded by bristles or hair to keep out dirt.
- Thin branching tubes **(tracheal tubes)** carry oxygen from air to all the parts. They are subdivided into **tracheoles** where **exchange** of **gases** takes place by **diffusion.** Very little CO_2 leaves through spiracles; majority of it leaves through cuticular covering of the body.

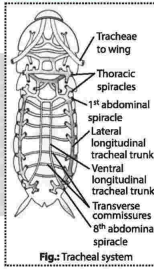


Fig.: Tracheal system

Reproductive System

- Cockroaches are **dioecious** *i.e.,* sexes are separate.
- **Male :** It has a pair of testes in 4th–6th abdominal segments which is 3-lobed and consists of numerous whitish transparent follicles. **Vas deferens** arise from testes and opens into **ejaculatory duct** through **seminal vesicles.**
- Ejaculatory duct opens into **male gonopore.** Sperms are stored in seminal vesicles in the form of bundles called **spermatophores** which are discharged during copulation.
- An accessory **mushroom shaped gland** is located in 6th-7th abdominal segments.
- **External genitalia** are represented by male gonapophyses or phallomeres.
- **Female :** Ovaries are located in 2nd –6th abdominal segments and are formed of a group of ovarian tubules **(ovarioles)** which contain a chain of developing **ova.**
- **Oviducts** from each ovary unite into single median oviduct which opens into genital chamber. A pair of **spermatheca** present in 6th segment also opens into genital chambers.
- Paired **collaterial glands** lie behind ovaries. Their secretion forms **egg-case** or **ootheca.**

Fertilisation and development

- Sperms are transferred in form of spermatophores. Fertilised eggs are encased in **ootheca,** which are reddish brown capsules and are dropped or glued to a humid surface. On average, females produce 9-10 oothecae, each containing 14-16 eggs.
- The development is **paurometabolous** *i.e.,* through nymphal stage.
- As nymphal development proceeds, wing pads arise, body increases in size, colouration becomes darker and ultimately after about 6-7 successive moults

Nervous System

- Nervous system comprises of central peripheral and sympathetic or somatogastric system.
- It comprises of fused, segmentally arranged ganglia joined by paired connectives on the ventral side. It bears **9 ganglia;** 3 ganglia lie in thorax and 6 in the abdomen.
- **Brain** is represented by bilobed supra-oesophageal ganglion which supplies nerves to antennae and compound eyes.
- **Compound eyes,** located dorsally, consists of **2000 hexagonal ommatidia** which make up **mosaic vision** of cockroach. This type of vision is common during night **(nocturnal vision),** with more sensitivity and less resolution.
- Other sense organs include **antennae, maxillary palps, labial palps, anal cerci,** etc.

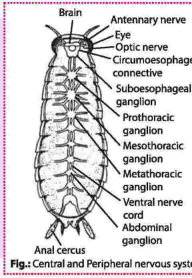
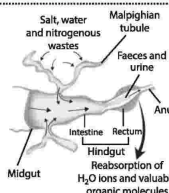


Fig.: Central and Peripheral nervous syste

Excretory System

- Excretion is performed by **Malpighian tubules** which are lined by glandular and ciliated cells. They absorb nitrogenous waste products and convert them into **uric acid** therefore insects are called **uricotelic.** They also reabsorb certain salts and water.
- **Fat body, nephrocytes** and **uricose glands** also help in excretion.



CONCEPT MAP

EARTHWORM

Pheretima posthuma or Indian Earthworm belongs to Phylum Annelida of Kingdom Animalia. It is terrestrial, living in burrows made in moist soil. It feeds on dead and decaying organic matter present in soil. Earthworm possesses great power of regeneration.

ANATOMY

Body wall

- Body wall consists of **cuticle, epidermis**, **muscular layer** and **parietal peritoneum**.
- Cuticle is thin, delicate, non-cellular and chitinous.
- Epidermis lies beneath cuticle and consists of **supporting** cells, **glandular** cells, **basal** cells, **receptor** cells and **setal** cells.
- Muscular layer consists of an outer layer of **circular muscles** and inner layer of **longitudinal muscles**.
- Parietal peritoneum is the innermost layer of body wall and forms outer boundary of coelom. It secretes **coelomic fluid**.

Coelom

- It is the space between the body wall and alimentary canal formed by splitting of embryonic mesoderm (**schizocoelom**). It is lined externally by the parietal peritoneum and internally by visceral peritoneum. It is filled with coelomic fluid.
- It is not a continuous cavity but is divided into compartments by transverse partitions called **septa**.
- Coelom consists of **phagocytes**, **circular** cells, **chloragogen** cells (excretory) and **mucocytes**.

Digestive system

- Alimentary canal is **complete** and **straight** tube.
- It is functionally regionated into various parts *viz.* buccal cavity, pharynx, oesophagus, gizzard, stomach, intestine and anus.
- **Mouth** leads to buccal cavity which extends from 1st to 3rd segment.
- **Oesophagus** extends from 5th to 7th segment and is dilated into **gizzard** in 8th segment.
- **Stomach** extends from 9th to 14th segment.
- **Intestine** is distinguished into **pretyphlosolar** region (15th-26th segment), **typhlosolar** region (from 27th segment upto 25 segments in front of anus) and **post-typhlosolar** region (in last 23 to 25 segments).
- Digestive glands associated with alimentary canal include: **pharyngeal gland** (present in roof of pharynx and secretes saliva), glandular cells of gastric epithelium and intestinal epithelium.

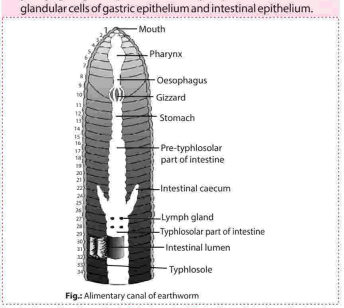
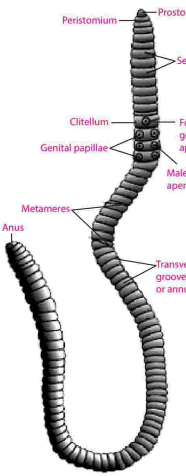


Fig.: Alimentary canal of earthworm



MORPHOLOGY

- Earthworm is bilaterally symmetrical, body is pointed in front and blunt behind.
- Mature worm measures about **150 mm** in length and **3 to 5 mm** in width.
- Body glistening deep brown or clay coloured (due to presence of **porphyrin** pigment in body wall).
- Dorsal surface carries a dark median line which is actually dorsal blood vessel beneath the skin.
- Body divided into 100-120 similar segments called **metameres** or **somites**.
- External segmentation corresponds with internal segmentation (**metamerism**).
- The first segment of body is termed as **peristomium** which bears **prostomium** anteriorly.
- **Clitellum** (circular band of glandular tissue) is found from 14th to 16th segments. Due to its presence, body is differentiated into **pre-clitellar**, **clitellar** and **post-clitellar** regions.
- Except the first, last and clitellar segments, each segment bears a ring of tiny curved, chitinous structures called **setae** or **chaetae**. Peristomium encloses a crescent shaped mouth and anus is situated in anal segment or **pygidium**.
- Female genital pore is situated on ventral surface of 14th segment. A pair of male genital pores lies on the ventral surface of 18th segment. Two pairs of **genital papillae** are present on the ventral surface of 17th and 19th segment (one pair in each segment). Four pairs of **spermathecal pores** are situated ventro-laterally in the intersegmental grooves of segments 5/6, 6/7, 7/8 and 8/9. **Nephridiopores** are scattered irregularly all over the body surface except first two segments.
- **Dorsal pores** located mid-dorsally one in each intersegmental groove, behind 12th segment.

Reproductive system

- Earthworms are **monoecious** but cannot fertilise their own eggs as they are **protandrous**.
- **Male reproductive system :** It includes **testes, testes sacs, seminal vesicles, vasa differentia, prostate glands** and **accessory glands.**
- Testes are 2 pairs (one in 10th and other in 11th segment) lying ventro-laterally beneath the alimentary canal, on either side of nerve cord. They produce spermatozoa.
- Each testis sac of 10th segment encloses a testis and a spermiducal funnel. Each testis sac of 11th segment encloses a testis, a seminal vesicle and a spermiducal funnel.
- Seminal vesicles are two pairs and receive spermatozoa produced by testes through testis sac. They help in maturation of spermatozoa.
- Vasa deferentia help in conduction of sperms.
- A pair of prostate glands are situated on either side of intestine and extend from 17th to 20th segment, their secretion serves as a medium for transfer of sperms.
- Accessory glands are present in 17th and 19th segments and open to exterior by genital papillae.
- **Female reproductive system:** It consists of **ovaries, oviducts** and **spermathecae**.
- A pair of ovaries are attached to the posterior surface of septum present between 12th and 13th segments. They produce ova. Oviducts are two short tubes each lying immediately behind respective ovary and open to outside by female genital pore.
- Four pairs of spermathecae open to outside through spermathecal pores situated ventro-laterally. They store sperms received from other earthworm during copulation.

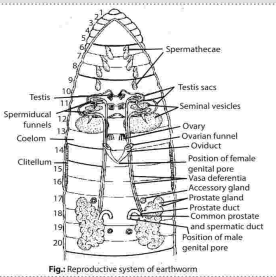


Fig.: Reproductive system of earthworm

Blood vascular system

- It is of **closed** type.
- Blood is composed of blood plasma containing respiratory pigment **haemoglobin** and blood corpuscles (**leucocytes**).
- Blood vessels include **dorsal** blood vessel, **ventral** blood vessel, **sub-neural** blood vessel, **lateral oesophageal** blood vessels and **supra-oesophageal** blood vessel.
- Four pairs of tubular hearts are present. These are provided with valves. Anterior 2 pairs of hearts are known as **lateral hearts** and posterior 2 pairs of hearts are called **latero-oesophageal** hearts.
- Spherical masses called **blood glands** are situated in 4th, 5th and 6th segments which produce blood corpuscles and haemoglobin.

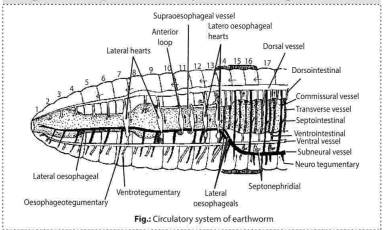


Fig.: Circulatory system of earthworm

Excretory system

- Earthworms are both **ammonotelic** and **ureotelic**.
- Nephridia perform the function of excretion and osmoregulation.
- According to their location nephridia are: **septal**, **pharyngeal** and **integumentary**.
- **Septal nephridia** – Occur in 15th segment onward. They are attached to septa and open internally, having **nephrostome**. Vary from 80-100 per segment and are largest in size. Enteronephric and remove metabolic wastes from blood and coelomic fluid.
- **Pharyngeal nephridia** – Occur in segments 4, 5 and 6. Lie on sides of gut in 3 paired groups. Closed internally, without nephrostome. Enteronephric and remove metabolic wastes from blood only.
- **Integumentary nephridia** – Occur in all segments except first two. Attached to body wall. Closed internally without nephrostome, Smallest in size, **ectonephric** and remove wastes from blood only.
- In addition, **chloragogen cells** also serve the function of excretion.

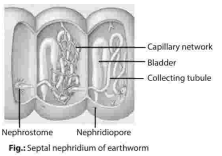


Fig.: Septal nephridium of earthworm

Nervous system

- Nervous system is well developed and consists of central, peripheral and autonomic nervous system.
- Central nervous system comprises of **supra-pharyngeal** (cerebral) **ganglia**, a pair of **peripharyngeal connectives**, a pair of **sub-pharyngeal ganglia** and **ventral nerve cord**. Ventral nerve cord has segmental ganglia.
- Nerves arising from the central nervous system and supplying various body parts constitute peripheral nervous system.
- Autonomic nervous system consists of an extensive nerve plexus situated beneath epidermis, within the muscles of body wall and on alimentary canal.
- Various receptors include tactile receptors, buccal receptors (chemo-receptors), photoreceptors.

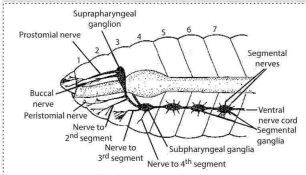


Fig.: Nervous system of earthworm

CONCEPT MAP

FROG

Frog belongs to the **Class Amphibia** of **Phylum Chordata**. Frogs are found around ditches, ponds, marshes, lakes and streams. They can live in water as well as on land hence called **amphibians.** The common Indian frog is ***Rana tigrina***.

Morphology

- Body of a frog is pointed anteriorly and rounded posteriorly. It is slightly flattened dorsoventrally, streamlined to swim through water and divisible into head and trunk without neck and tail.
- Skin of frog is thin, moist, smooth, slimy and green coloured with black or brown spots dorsally and lighter pale yellow ventrally. There are no scales or any other hard exoskeleton parts.
- Skin of back has dorsolateral folds or thickenings called **dermal plicae**.
- Head is roughly triangular with a short **blunt** anterior **snout** terminating in a large transverse **mouth.** It bears external nares or nostrils, eyes, brow spot and ear drums on the upper side.
- Frogs have two large and protruding eyes, having an almost immovable upper eyelid and a thin semi-transparent and freely movable lower eyelid. From lower eyelid arises **nictitating membrane** that protects eyes during swimming.
- **Vocal sacs** act as resonators to intensify sound of croaking during breeding season.
- Trunk consists of **thorax, abdomen** and a pair of forelimb and hindlimb.
- Frog shows **sexual dimorphism** as male frog possesses developed **vocal sacs** and **nuptial pad** during breeding season and their body is somewhat slender and darker in colour than female frog.

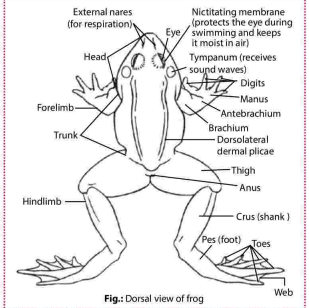


Fig.: Dorsal view of frog

Anatomy

Circulatory System

- Circulatory system of frog is closed and includes **heart**, **arterial system**, **venous system**, **blood** and **lymphatic system**.
- Heart is **three chambered** made up of two anterior **atria** or **auricles** and a single posterior **ventricle**. Two additional chambers are **sinus venosus** and **truncus arteriosus.**
- The two auricles, right (larger) and left, are completely separated from each other by **inter-auricular septum.** Both auricles open into single ventricle by a common large **auriculo-ventricular aperture** guarded by two pairs of **auriculo-ventricular valves.**
- The inner surface of ventricle has irregular ridges called **columnae carneae** or **trabeculae**, with depressions called **fissures**.

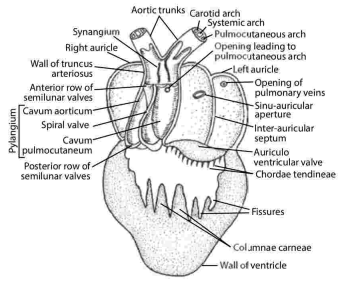


Fig.: Internal structure of heart of frog (ventral view)

Digestive System

- The digestive system mainly consists of **alimentary canal** and its associated **glands.**
- Mouth leads into a buccopharyngeal cavity which opens into oesophagus through gullet.
- **Stomach** is situated behind the oesophagus and divisible into cardiac stomach and pyloric stomach.
- The small intestine is divisible into an anterior **duodenum** and a posterior **ileum**. Digestion of food and absorption of digested food occur in the small intestine.
- Ileum leads to **rectum** or large intestine. The rectum opens into the **cloaca** through the **anus.**
- **Digestive glands** of frog include liver, pancreas, gastric glands and intestinal glands.

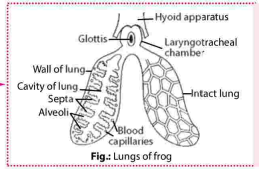


Fig.: Lungs of frog

Respiratory System

Adult frog respires by three different types of respiration:

- **Cutaneous respiration :** It occurs through the highly vascular skin of frog in water or land.
- **Buccopharyngeal respiration :** It occurs on land or during partial immersion in water *via* mucous epithelial lining of buccopharyngeal cavity.
- **Pulmonary respiration :** It is less frequent and takes place through lungs in adult frog when the frog is outside the water.

Nervous System

- It is highly developed and comprises of:
  - **Central nervous system** (CNS) includes brain and spinal cord. **Brain** is covered by two meninges; duramater (outer) and pia-arachnoid (inner). Brain is divisible into three parts: Forebrain, midbrain and hindbrain. **Spinal cord** is located in the vertebral column and joins the medulla oblongata *via* **foramen magnum** of the cranium (brain case).
  - **Peripheral nervous system** (PNS) includes 10 pairs of **cranial nerves** and 9 pairs of **spinal nerves .** Rarely 10th (paired or unpaired) spinal nerve is found.
  - **Autonomic nervous system** is made up of sympathetic and parasympathetic nerves which controls and coordinates the involuntary activities of the visceral organs.
- Five types of sense organs are **skin** (tangoreceptor), **taste buds** (gustatoreceptor), **nasal chambers** (olfactoreceptor), **eyes** (photoreceptor) and **ears** (stato-acoustic organs).

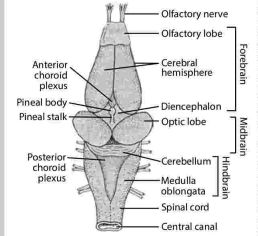


Fig.: Dorsal view of brain of frog

Urinogenital System

- In frogs, the excretory and reproductive systems are closely associated, hence they are together called urinogenital system.
- **Excretory system** comprises of kidneys, ureters in females, urinogenital ducts in males, cloaca and urinary bladder. Kidneys are the chief excretory organs which are made up of large number of **uriniferous tubules** or nephrons.
- From the kidneys, arise **ureter** in females and **urinogenital duct** in males.
- Cloaca receives faecal matter, genital products and urine (from kidney). Ventrally it is attached to urinary bladder.
- In **males,** near each kidney there is a cylindrical **testis** from which several thin **vasa efferentia**, connecting the testes to kidneys on each side. The vasa efferentia run transversely through mesorchium and open into the **Bidder's canal** which in turn opens into the **ureter.** Histologically, each testis is a compact mass of seminiferous tubules, the epithelial lining of which produces **sperms.** The sperms when mature are dropped into the lumen to pass into the ureter through vasa efferentia and Bidder's canal.
- **Females** have two ovaries where ova are produced by ovarian follicles. On each side of an ovary is an oviduct which starts posteriorly and forms uterus, which opens into the cloaca. During breeding season ova are released into the coelom and then they reach the ovarian funnels from where they pass to the ovisacs, cloaca and then outside.
- Egg of frog is **telolecithal**.

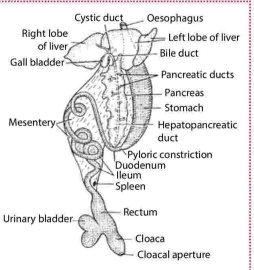


Fig.: Alimentary canal (except buccopharyngeal cavity) of frog

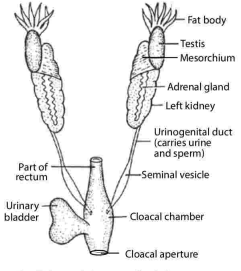


Fig.: Urinogenital system of male frog

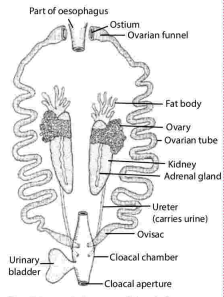


Fig.: Urinogenital system of female frog

CONCEPT MAP

NITROGEN NUTRITION IN PLANTS

Nitrogen is one of the most important nutrient required for proper growth of the plants as it is present in the compounds like proteins, amino acids, alkaloids, vitamins, enzymes, chlorophyll and nucleic acids. Its deficiency causes chlorosis and stops cell division and elongation thus retards growth.

Atmospheric nitrogen

- It is available in atmosphere in high amount (78%) in the form of (dinitrogen gas, N_2).
- It is the most critical element for plant growth.

Nitrogen fixation

- Plants directly cannot absorb N_2 from air because its acquistion from atmosphere requires breaking of an exceptionally stable triple covalent bond between two nitrogen atoms (N≡N).
- Thus, it must be **'fixed'** into utilizable forms *i.e.*, ammonia (NH_3) or nitrate (NO_3^-).

Abiological nitrogen fixation

- Abiological fixation occurs naturally or by industrial processes.
- **Natural fixation** occurs by electric discharge, ozonisation and combustion.
- Different types of oxides of nitrogen are formed, which ultimately come to the soil by the means of mixing with rain water.

$$N_2 + O_2 \xrightarrow{\text{Electric discharge}} 2NO_2 \text{ (Nitrogen oxide)}$$

$$2NO + 2[O] \xrightarrow[\text{Ozonisation}]{\text{Electric discharge}} 2NO_2$$

$$2NO + 3[O] \xrightarrow{\text{Ozonisation}} N_2O_5$$

$$H_2O + 2NO \rightarrow HNO + HNO_2$$

$$H_2O + 2NO_2 \rightarrow HNO_2 + HNO_3$$

$$H_2O + N_2O_5 \rightarrow 2HNO_3$$

- **Industrial fixation** involves production of ammonia by directly mixing nitrogen with hydrogen (from water) under high pressure and temperature.
- Various fertilisers are produced industrially to provide nitrogen to the plants.

Biological nitrogen fixation

- It is the major source of nitrogen fixation and is done by prokaryotes (bacteria and cyanobacteria), either free living (asymbiotic) or symbiotic.
- **Asymbiotic nitrogen fixation** is done by free living bacteria like *Azotobacter, Klebsiella*, etc. and cyanobacteria like *Anabaena, Nostoc* and *Trichodesmium.*
- **Symbiotic nitrogen fixation** is done by symbiotic prokaryotes inside the body of their plant hosts. *Nostoc, Anabaena* and *Anthoceros* etc. are symbiotic nitrogen fixing cyanobacteria, whereas *Rhizobium* and *Frankia* etc. are symbiotic nitrogen fixing bacteria.
- *Rhizobium* (in legume) and *Frankia* (in non legume plants) can fix nitrogen in anaerobic conditions by nodule formation.
- **Nodules** require cooperation of ***nod, nif*** and ***fix*** gene clusters of bacteria for their formation.
- Roots of the legume secrete chemical attractants **(flavonoids and betaines).** Bacteria collect over the root hairs and release *nod* factors that cause curling of root hair around the bacteria.
- An infection thread enclosing bacteria is constructed by the root cells in response to the infection. When it reaches deep in the cortex, it bursts and the rhizobia are engulfed into membrane enclosed **symbiosomes** within the cytoplasm.
- Synthesis of **auxin** from cortical cells and cytokinin from associating bacteria stimulate nodule formation. Bacteria form irregular polyhedral structures *i.e.,* **bacteroids** inside nodules.
- The legume host supplies nitrogenase, the nitrogen fixing enzyme which is strongly inhibited by oxygen. **Leghaemoglobin** (Lb) an oxygen scavenger is present in nodules which protects nitrogenase.

Assimilation of nitrate

- Nitrate is the most important source of nitrogen to the non legume plants. It is not used by plants as such but is stepwise reduced to the level of ammonia before being incorporated into organic compounds.
- Firstly **nitrate reductase,** an inducible enzyme (having molybdoflavoprotein) favours the formation of reduced nitrite in the presence of reduced coenzyme.

$$NO_3^- + NAD(P)H + H^+ + 2e^- \xrightarrow[\text{FAD/FMN}]{\text{Nitrate reductase}} NO_2^- + H_2O + NAD(P)$$

- Then an enzyme **nitrite reductase** (metalloflavoprotein containing copper and iron) favours the formation of nitrite under reduced condition.

$$2NO_2^- + 7NAD(P)\,H + 7H^+ \xrightarrow[\text{Ferrodoxin}]{\text{Nitrite reductase}} 2NH_3 + 4H_2O + 7NAD(P)^+$$

- Formed ammonia is not liberated. It combines with acid to form amino acids and is utilised in making various types of nitrogenous compounds (*As discussed under 'Assimilation of ammonia'*).

Mechanism of biological nitrogen fixation

- It requires :
  - (i) $FMNH_2$, $NADPH_2$ etc. as reducing power
  - (ii) Nitrogenase and hydrogenase enzymes
  - (iii) ATP as source of energy
  - (iv) Compound for trapping released ammonia
  - (v) Leaghaemoglobin for protection of nitrogenase from O_2
  - (vi) Presence of non haeme iron protein ferrodoxin as electron carrier
  - (vii) Presence of cofactors CoA, TPP, Pi, Mg^{2+}, Co and Mo etc
- The overall reaction is shown as :

$$N_2 + 8e^- + 8H^+ + 16\,ATP \longrightarrow \underset{\text{(Ammonia)}}{2NH_3} + 2H^+ + 16\,ADP + 16\,Pi$$

Nitrification

- Ammonia thus produced gets readily converted to nitrates by various microorganisms.
- It takes place in two steps. First ammonia is oxidised to nitrites and then nitrites are oxidised to nitrates by different microorganisms.

$$2NH_3 + 3O_2 \xrightarrow[\text{Aspergillus flavus}]{\text{Nitrosococcus, Nitrosomonas}} 2NO_2^- + 2H^+ + 2H_2O + \text{Energy}$$

$$2NO_2^- + O_2 \xrightarrow[\text{Nitrocystics}]{\text{Nitrobacter, Penicillium}} 2NO_3^- + \text{Energy}$$

- Bacteria performing nitrification are **chemoautotrophs** which utilise the energy released during the reaction for the synthesis of organic substances.

Assimilation of fixed nitrogen

- Plants get fixed nitrogen from the two sources– symbiotic and asymbiotic.
- In case of symbionts, the **ammonia** is taken up by host immediately and assimilated; while in case of free living nitrogen fixers the fixed nitrogen is released by their death and decay in the form of **nitrates** through **ammonification** and **nitrification.**

Ammonification

- Decay causing organisms *e.g., Bacillus ramosus, B. vulgaris*, and actinomycetes convert dead bodies of microorganisms as well as other soil organic matter (excreta and dead body of other animals) into organic acid and ammonia.

$$\text{Protein} \xrightarrow{H_2O} \underset{\text{(Amino acid)}}{R - NH_2} \xrightarrow{H_2O} \underset{\text{(Organic acid)}}{ROH} + \underset{\text{(Ammonia)}}{NH_3}$$

Assimilation of ammonia

- Ammonia is **toxic** to plants and thus is readily converted to amino acids.
- The primary pathway for this conversion involves sequential actions of glutamine synthetase and glutamate synthetase *i.e.,* **catalytic amidation.**

$$\text{Glutamate} + NH_4^+ + ATP \xrightarrow[\text{synthetase}]{\text{Glutamine}} \text{Glutamine} + ADP + Pi$$

$$\text{Glutamine} + \alpha\text{-Ketoglutaric acid} + NAD(P) \xrightarrow[\text{synthetase}]{\text{Glutamate}} 2\,\text{Glutamate} + NAD(P)$$

- In an alternative pathway, glutamate dehydrogenase catalyses a reversible reaction that synthesises glutamate *i.e.,* **reductive amination.**

$$\alpha\text{- Ketoglutaric acid} + NH_4^+ + NAD(P)H \xrightarrow[\text{dehydrogenase}]{\text{Glutamate}} \text{Glutamate} + H_2O + NAD(P)$$

- Once assimilated into glutamate, nitrogen is incorporated into other amino acids *via* **transamination** reactions catalyzed by **aminotransferases.** *E.g.,*

$$\text{Glutamic acid} + \text{Oxaloacetic acid} \xrightarrow[\text{aminotransferase}]{\text{Glutamate aspartate}} \alpha\text{-Ketoglutaric acid} + \text{Aspartic acid}$$

- **Amides** (principally asparagine or glutamine) are generally used as a medium of translocation and storage of nitrogen because of their stability and high nitrogen to carbon ratio. In some legumes *e.g.,* soyabean, **ureides** (allantoin, allantonic acid and citrulline) are used for the purpose.
- The proteins through food chain get converted into animal proteins. By death and decay of both plant and animal organic matter (ammonification and nitrification) the nitrogen cycle continues in the environment.

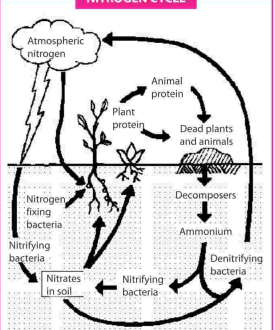
Denitrification

- In anaerobic condition, some microbes reduce nitrates to gaseous compounds of nitrogen which release from the soil.

$$2NO_3^- \rightarrow 2NO_2^- \rightarrow 2NO \rightarrow N_2O \rightarrow N_2$$

- Denitrification is mainly carried out by *Pseudomonas denitrificans, Thiobacillus denitrificans* and *Micrococcus denitrificans.*
- It depletes the soil of an important nutrient and causes acidification and leads to the solubilisation of harmful metals. Dentrification has a role in nitrogen cycle as it supplies nitrogen to its reservoir pool, the atmosphere.

NITROGEN CYCLE



CONCEPT MAP

CELLULAR RESPIRATION

- Cellular respiration is the oxidative breakdown of food materials within the cell which releases energy and biochemical intermediates.
- The energy is used in the synthesis of ATP and the biochemical intermediates are used for synthesis of organic compound that take part in growth, repair and metabolism.

ATP BALANCE SHEET

Stage	ATP by substrate phosphorylation	Formation of $NADH/FADH_2$	ATP through ETS in mitochondria
Glycolysis in cytoplasm	2	2 NADH (one NADH on oxidation) through ETS form 3 or 2 ATP depending upon shuttle system.	2 × 3 = 6
Formation of acetyl CoA in matrix of mitochondria	–	2 NADH	2 × 3 = 6
Krebs cycle	2	2 FADH2 6 NADH	2 × 2 = 4 6 × 3 = 18
	4		34(or 32)

Total net gain of ATP = 36 or 38 depending upon type of aerobic respiration.

ANAEROBIC RESPIRATION

- It is a type of respiration in which oxygen is not used as an oxidant and the organic food is broken down incompletely to liberate energy, by breaking of bonds between various types of atom.
- The common products of anaerobic respiration are **CO_2, ethyl alcohol** and **lactic acid**.
- Under anaerobic conditions, in lactic acid bacteria, fungi, some muscles, pyruvate is directly reduced by NADH to lactic acid, in the presence of the enzyme lactate dehydrogenase.

$$\text{Pyruvic acid} + \text{NADH} \xrightarrow[\text{FMN, Zn}^{2+}]{\text{Lactate dehydrogenase}} \text{Lactic acid} + \text{ATP}$$

- In yeast, pyruvate is broken down to ethyl alcohol and CO2 by sets of reactions in the presence of enzymes pyruvate decarboxylase and alcohol dehydrogenase.

$$\text{Pyruvate} \xrightarrow[\text{decarboxylase, TPP, Mg}^{++}]{\text{Pyruvate}} \text{Acetaldehyde} \xrightarrow[\text{NADH}]{\text{Alcohol dehydrogenase}} C_2H_5OH + NAD^+$$

AEROBIC RESPIRATION

- The oxidnative breakdow of respiratory substrates with the help of atmospheric oxygen is known as **aerobic respiration**.
- It involves complete breakdown of substrates into CO_2 and water and release of lot of energy.

$$C_6H_{12}O_6 + 6O_2 \xrightarrow{\text{Enzymes}} 6CO_2 + 6H_2O + 686\ \text{KCal}$$

- The common pathway of aerobic respiration consists of three steps: glycolysis, Krebs cycle and terminal oxidation.

Glycolysis

- It is the process of partial oxidation of glucose or similar hexose sugar into two molecules of pyruvic acid through a series of ten enzyme mediated reactions, releasing energy as ATP and reducing power as $NADH_2$.
- It occurs in cytosol or cytoplasm.
- It is common to both aerobic and anaerobic respiration.
- It is regulated by three enzymes, catalysing non-equilibrium reactions: **hexokinase, phosphofructokinase** and **pyruvate kinase**.

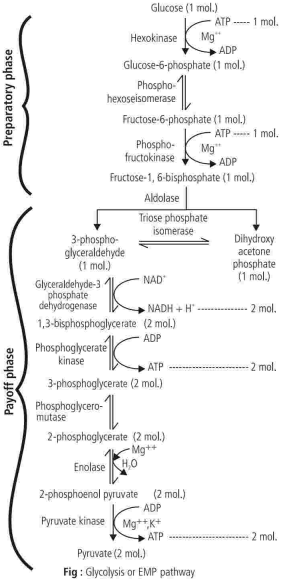


Fig : Glycolysis or EMP pathway

Terminal Oxidation

- It occurs towards the end of catabolic process.
- Involves passage of both electrons and protons of reduced co-enzymes to oxygen and produces water.
- Consists of two processes – **electron transport chain** and **oxidative phosphorylation**.
- An electron transport chain or system is a series of coenzymes and cytochromes that take part in passage of electrons from a chemical to its ultimate acceptor.
- In electron transport chain, the reducing equivalents from various metabolic intermediates are transferred to coenzymes NAD^+ and FAD to produce NADH and $FADH_2$ respectively.
- Oxidative phosphorylation is the synthesis of energy rich ATP molecules with the help of energy liberated during oxidation of reduced co-enzymes (NADH, $FADH_2$) produced in respiration. The enzyme required for this synthesis is called **ATP synthase**.

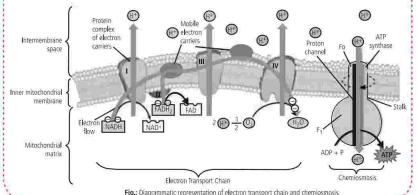


Fig.: Diagrammatic representation of electron transport chain and chemiosmosis

Krebs Cycle

- Pyruvate formed in glycolysis undergoes oxidation to get converted to **acetyl CoA**.
- It is catalysed by multi-enzyme **pyruvate dehydrogenase complex (PDH)**.
- In this reaction (highly exergonic and irreversible *in vivo*) carboxyl group of pyruvate is lost as CO_2 while the remaining two carbons form acetyl CoA.

$$\text{Pyruvate} + \text{CoA} + NAD^+ \xrightarrow{\text{Pyruvate dehydrogenase complex}} CO_2 + \text{Acetyl CoA} + NADH + H^+$$

- Pyruvate oxidation is the gateway step or **link reaction** as acetyl CoA acts as a connecting link between glycolysis and Krebs cycle.
- Krebs cycle is also known as Citric acid cycle.
- It is a nearly universal central catabolic pathway in which compounds derived from the breakdown of carbohydrates, fats and proteins are oxidised to CO_2.
- It occurs in mitochondrial matrix.
- The Citric acid cycle is **amphibolic** since in addition to oxidation it is important in provision of carbon skeletons, for gluconeogenesis, fatty acid synthesis and interconversion of amino acids.

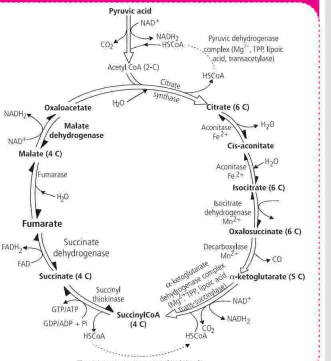


Fig.: Schematic representation of Krebs' cycle

CONCEPT MAP

PHYTOHORMONES

Phytohormones refer to a chemical substances other than nutrient molecules produced naturally in plants. They may be translocated to another region and are capable of regulating one or more physiological reactions, when present in low concentrations.

PHYTOHORMONES

Plant growth regulators or hormones are broadly classified into two categories.

Growth Promoting Hormones

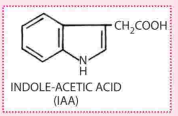
Auxin

Nature: Weakly acidic growth hormone having an unsaturated ring structure. Auxins refer to natural (IAA, PAA, IAN) and synthetic (Indole 3-butyric acid, NAA, 2, 4-D, 2, 4, 5-T) compounds having similar structure and properties.

Discovery: Darwin (1880) was first to find sensation of unilateral illumination in the coleoptile tip of canary grass. Later Kogl and Smith (1931) isolated three chemicals from human urine which they named as auxin a , auxin b and hetero auxin. **IAA** is the universal natural auxin.

Location: It is found in shoot apices, leaf primordia and developing seeds and is synthesised from amino acid **tryptophan**, a precursor of IAA or auxins.

Bioassay: Avena curvature test and root growth inhibition test are done for examining auxin effect.



INDOLE-ACETIC ACID (IAA)

Physiological functions:

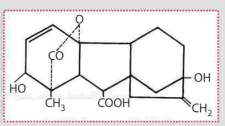
- Promotes cell enlargement and division and initiates root formation on stem cuttings.
- Cambial activity and xylem differentiation is also regulated by auxins.
- Shows apical dominance *i.e.*, inhibits the growth of lateral buds.
- Prevents or delays abscission as well as induces synthesis of ethylene.
- Produces tropic plant responses like phototropism and geotropism.
- Shows feminising effect on some plants.

Commercial uses:

- In tissue and organ culture to form callus and initiate rooting.
- To produce parthenocarpic fruits.
- Auxins like 2, 4-D and 2, 4, 5-T acts as weedicides by being selectively harmful to broad leaved dicot weeds.
- Induces flowering in litchi and pineapple.
- NAA increases the number of dwarf shoots and fruits on them.
- Prevents pre-harvest fruit drop of orange and apple (by low concentration of 2, 4-D) and tomato (by NAA)

Gibberellin

Nature: Weakly acidic growth hormone having gibbane ring structure.



Discovery: Hori and Kurosawa discovered the active substance from filtrate of fungus, *Gibberella fujikuroi* (causing bakane disease in rice plants) and named it gibberellin. **GA_3** was first gibberellin to be isolated in its pure form and remains the most extensively studied.

Location: The major sites of gibberellin production in plants are embryos, roots and young leaves near the shoot tip. **Mevalonic acid** (derived from acetyl Co-A) acts as precursor for synthesis of gibberellins. It is transported through simple diffusion as well as *via* conducting channels.

Bioassay: Barley endosperm test and germination of dwarf pea seeds are used as bioassays.

Physiological functions:

- Stimulates stem elongation and leaf expansion.
- Overcome natural dormancy of buds, tubers, seeds etc.
- Induces elongation of reduced stem or bolting in rosette plants *e.g.*, henbane, cabbage.
- Promotes seed germination by inducing production of hydrolytic enzymes for solubilising reserve food.
- Promotes flowering in long day plants during non-inductive period.
- Controls fruit growth and development as well as induces parthenocarpy.
- Promotes formation of male flowers on female plants *e.g., Cannabis*. They can also replace female flowers with male ones on monoecious plants of cucurbits.

Commercial uses:

- Exogenous application of GA_4 and GA_7 mixture to increase the number and size of fruits *e.g.*, apple, grapes, tomato.
- Production of seedless pomaceous fruits by parthenocarpy.
- GA_7 delays senescence of fruits and delays its ripening thus, extending its shelf life and storage period.
- Induces offseason flowering in many long day plants as well as those requiring vernalisation.
- Application of gibberellins increases length of stem and yield of sugarcane.
- Promotes early maturity resulting in seed production in juvenile conifers.

Cytokinin

Nature: These are basic hormones, being derivatives of either **aminopurine** or **phenyl urea** that promote cytokinesis.

Discovery: The first cytokinin was discovered from autoclaved herring sperm DNA which stimulated cell division in tobacco pith cells. It is called **kinetin** and does not occur naturally in plants.

The first natural cytokinin was obtained from unripe maize grains, called **zeatin** (6-hydroxy 3-methyl trans 2-butenyl amino purine).

It is found in coconut milk.

Zeatin

Location: It is mainly found in roots, however it is also synthesised in endosperm regions of seeds, growing embryos, young fruits and developing shoot buds.

Bioassay: Tobacco pith culture, retardation of leaf senescence and excised radish cotyledon expansion are used as bioassays for cytokinins.

Physiological functions:

- Promotes cell division.
- Essential for morphogenesis and differentiation of tissues and organs.
- Delays senescence by mobilisation of nutrients.
- Overcome apical dominance caused by auxins and promote lateral bud development.
- Induces accumulation of salts inside cells and help in phloem transport.
- Promotes femaleness in flowers.

Commercial uses:

- Forms essential component of tissue culture as required for morphogenesis.
- Application of cytokinin increases the shelf life of flowers and vegetables, keeping them fresh for longer periods.
- Helps in developing resistance to pathogens and extremes of temperature, in plants.
- Delays senescence of intact plant parts.

Growth Inhibiting Hormones

Ethylene

Nature: It is the only gaseous phytohormone which stimulates transverse or isodiametric growth but retards the longitudinal one.

Discovery: R. Gane (1934) found that substance causing ripening was ethylene. But it was recognised as a plant hormone by Crocker *et al* (1935).

Location: It is found in almost all parts of plants in minimal amount but maximum production occurs during ripening of fruits and in tissues undergoing senescence. It is synthesised from amino acid **methionine** in plants.

Bioassay: The 'triple response' of etiolated pea plant and gas chromatographic assay are used as bioassays.

Physiological functions:

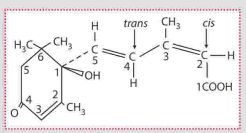
- Promotes apical dominance and prolongs dormancy of lateral buds but breaks the dormancy of buds, seeds and storage organs.
- Induces abscission and senescence of various parts *i.e.*, leaves, flowers and fruits etc.
- Induces epinasty, a phenomenon which decreases the sensitivity to gravity.
- Helps in root initiation, growth of lateral roots and root hairs.
- Stimulates flowering in pineapple and other related plants and helps in synchronising fruit set.
- Induces ripening of fleshy climacteric fruits and dehiscence of dry fruits.

Commercial uses:

- Ethylene lamps are used for ripening of fleshy fruits *e.g.*, banana, mango, apple, tomato.
- Ethylene is used to induce feminising effect *e.g.*, number of female flowers and thus fruits in cucumber.
- Ethylene also permits thinning of excess flowers and young fruits so as to allow better growth of remaining fruits.

Abscisic Acid

Nature: It is a mildly acidic growth hormone which acts as a general growth inhibitor. It is also called as **stress hormone** since its production is stimulated under conditions of drought, water logging and adverse environmental conditions.



Discovery: The hormone was first isolated by Addicott *et al* (1963) from cotton bolls.

Location: It is found in many parts of the plant but is more abundant in chloroplast of green cells. It is synthesised from **mevalonic acid** or **xanthophyll**.

Bioassay: Rice seedling growth inhibition test and inhibition of α-amylase synthesis in barley endosperm are used as bioassay.

Physiological functions:

- Induces dormancy of buds, seeds and underground stems, hence also called as **dormin**.
- Promotes abscission of flowers and fruits.
- Induces senescence of leaves by promoting degradation of chlorophyll and proteins.
- Stops cambium activity (in vascular cambium) towards the approach of winter.
- Inhibits seed germination by inhibiting gibberellin mediated amylase formation.
- It is antagonist to gibberellin and counteracts the effect of growth promoting hormones-auxins and cytokinins.

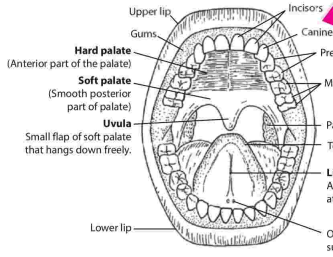
Commercial uses:

- Used as antitranspirant (as application of even minute quantities of ABA on leaves causes partial closure of stomata), thus, preventing transpiration as well as reducing photosynthesis.
- Induces flowering in some short day plants, even under unfavourable photoperiods.
- External application on stem cuttings initiate rooting.
- Induces parthenocarpic development in rose.
- Used in prolonging dormancy of buds, storage organs and seeds.

CONCEPT MAP

HUMAN DIGESTIVE SYSTEM

Humans show holozoic nutrition wherein they feed by ingesting complex organic matter. They have a specialised digestive system. The organic matter is subsequently digested and absorbed in this system. The human digestive system includes a long tube like gastrointestinal (GI) tract or alimentary canal (approximately 9 m in adults) and digestive glands. The GI tract runs through the body from mouth to anus. Each region of this tract is specialised to carry out particular steps in digestion and allow movements of its contents.



Hard palate (Anterior part of the palate)

Soft palate (Smooth posterior part of palate)

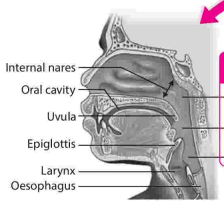
Uvula Small flap of soft palate that hangs down freely.

Lingual frenulum A fold through which tongue is attached to the floor of cavity

Oral cavity/ Buccal cavity (Opening of mouth is guarded by two movable lips that lead to oral cavity.)

Mouth

Pharynx A common passageway for solid food, liquids and air. It is divisible into 3 parts.

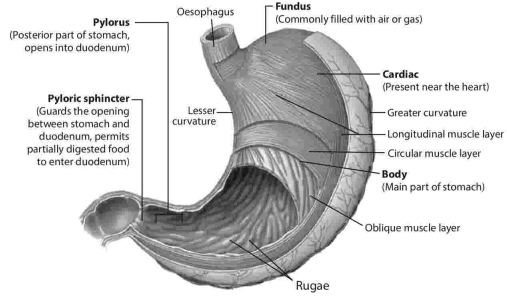


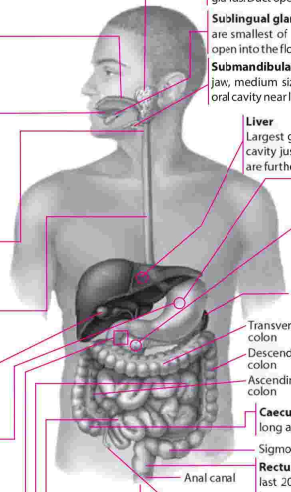
Regions of the pharynx
- Nasopharynx
- Oropharynx
- Laryngopharynx

Oesophagus About 25 cm, narrow, thick walled muscular tube leading from pharynx to the stomach (transfers food).

Gall bladder Pear shaped, sac like structure, attached to posterior surface of the liver. It stores bile secreted by the liver.

Stomach J-shaped organ, comprises of two curvatures. It has four parts.





Parotid gland- Located near the ears and are largest of the three glands. Duct opens into the oral cavity near upper second molars.

Sublingual gland - They are located beneath the tongue and are smallest of three glands. Their ducts **(ducts of Rivinus)** open into the floor of oral cavity.

Submandibular glands - They are located at angles of lower jaw, medium sized. Their ducts **(Wharton's duct)** open into oral cavity near lower central incisors.

Salivary glands Discharge their secretion into the oral cavity. Secrete salivary amylase and mucus.

Liver Largest gland of the body, lies in the upper right side of abdominal cavity just below the diaphragm. Divided into two main lobes which are further subdivided into **lobules**, the functional unit of liver.

Pancreas Soft, lobulated, greyish-pink gland, located posterior to the stomach in the abdominal cavity. It comprises of both exocrine and endocrine cells.

Spleen

Colon Possess three longitudinal bands called **taeniae coli** and small pouches called **haustra**. It contains microbial flora.
- Transverse colon
- Descending colon
- Ascending colon

Caecum- Pouch like structure, about 6 cm long and leads to colon.

Sigmoid colon

Rectum - Short muscular tube, comprising last 20 cm of gut and terminates in 2 cm long anal canal.

Anal canal

Appendix- Outgrowth of caecum, slightly coiled blind tube and vestigial in humans. Its wall contains prominent lymphoid tissue.

Anus Opening of anal canal, guarded by internal anal sphincter and external anal sphincter.

Large intestine Large in diameter than small intestine. It is about 1.5 m long and divisible into three parts.

Ileum (means roll or coil) It is the longest part of small intestine (approximately 3.5 m), with a diameter of 3.5 cm. Along the ileum, clusters of nodules called **Peyer's patches** are present.

Jejunum (means empty) Thick walled, vascular, middle of small intestine, about 2.5 m long with a diameter of 4 cm.

Duodenum C-shaped, thin walled, shortest and widest part of small intestine. Numerous special submucosal glands-**Brunner's gland** are present in which empty thin ducts into the **crypts of Lieberkuhn**. They also show numerous finger like projections called **villi** that increase the absorptive surface considerably.

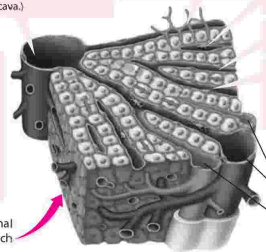
Small intestine Small in diameter but longest part of the alimentary canal, usually 5-6.25 m long. Length varies according to the height of individual and not with weight. Possesses prominent circular folds of mucous membrane- **plicae circulares** or **valves of Kerckring**.

DIGESTIVE GLANDS

Central vein (Located at centre of each lobule, drains blood from lobules and merge to form hepatic vein that empties into vena cava.)

Bile canaliculi (Network of tubular spaces between liver cells)

Kupffer cell (Phagocytic cells, lie along the endothelium of sinusoids at intervals)

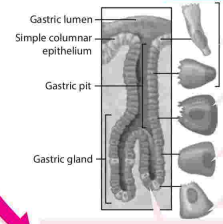


Hepatic sinusoid (Capillary surrounded by liver cells)

Hepatocytes (Liver cells, take up nutrients and other substances from sinusoids, synthesise and secrete bile into bile canaliculi).

Portal triad :
- Branch of bile duct
- Branch of hepatic portal vein
- Branch of hepatic artery

Gastric glands



Mucous or Goblet cells (Present throughout the epithelium and secrete mucus)

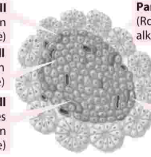
Parietal or Oxyntic cell (Lies against the basement membrane and secretes hydrochloric acid and Castle's intrinsic factor)

Chief cell or peptic cell (Secretes pepsinogen and small amount of gastric amylase and gastric lipase)

G-cell or gastrin cell (Secretes and stores hormone gastrin)

Argentaffin cells (Produce and secrete serotonin, somatostatin and histamine)

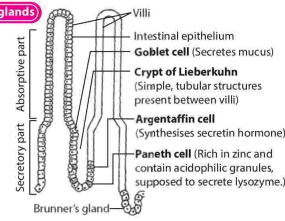
Islet of Langerhans (Endocrine part)
- **Alpha cell** (Secretes glucagon hormone)
- **Beta cell** (Secretes insulin hormone)
- **Delta cell** (Secretes somatostatin hormone)



Pancreatic acini (Rounded lobules, secrete alkaline pancreatic juice) — Exocrine part

F cell or Pancreatic polypeptide cell (Secretes pancreatic polypeptide that inhibits the release of pancreatic juice)

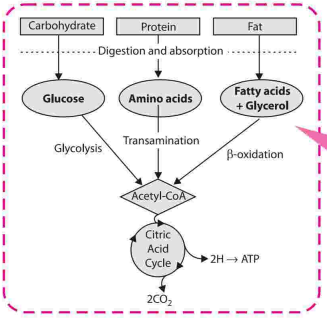
Intestinal glands



CONCEPT MAP

METABOLISM

- **Metabolism is a highly coordinated cellular activity** in which many multi-enzyme systems **(metabolic pathways)** cooperate to (i) Obtain chemical energy by capturing solar energy or degrading energy-rich nutrients from the environment; (ii) Convert nutrient molecules into the cell's own characteristic molecules, including precursors of macromolecules; (iii) Polymerise monomeric precursors into macromolecules: proteins, nucleic acids, and polysaccharides; and (iv) Synthesise and degrade biomolecules required for specialised cellular functions, such as membrane lipids, intracellular messengers and pigments.
- Metabolic pathways fall into three categories: (i) **Anabolic pathways,** which are those involved in the synthesis of larger and more complex compounds from smaller precursors; (ii) **Catabolic pathways,** which are involved in the breakdown of larger molecules, commonly involving oxidative reactions; and are exothermic and (iii) **Amphibolic pathways,** which occur at the "crossroads" of metabolism, acting as links between the anabolic and catabolic pathways, *e.g.,* the Citric acid cycle.

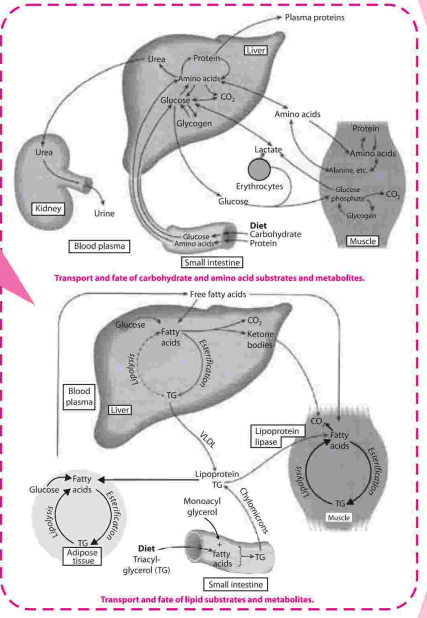


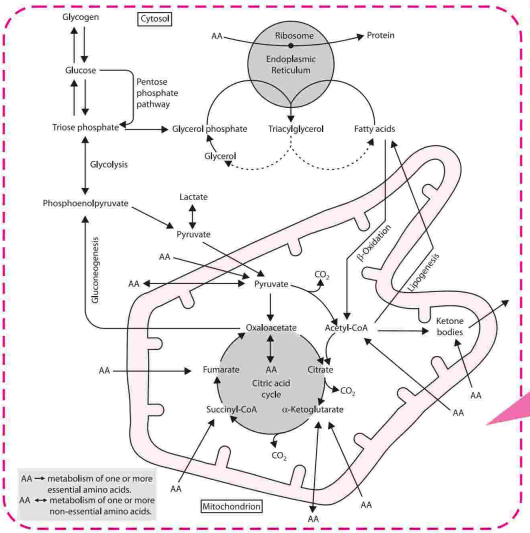
Metabolism of Carbohydrates, Proteins and Lipids

- The products of digestion of dietary carbohydrates, lipids and proteins are glucose, fatty acid + glycerol and amino acids, respectively.
- All the products of digestion are metabolised to a common product, **acetyl-CoA,** which is then oxidised by the Citric acid cycle.
- Glucose is metabolised to pyruvate by the pathway of **glycolysis.** Aerobic tissues metabolise pyruvate to acetyl-CoA, which can enter the Citric acid cycle for complete oxidation to CO_2 and H_2O, linked to the formation of ATP in the process of oxidative phosphorylation. Glycolysis can also occur anaerobically when the end product is **lactate.**
- Fatty acids may be oxidised to acetyl-CoA by β-oxidation or esterified with glycerol, forming **triacylglycerol** (fat) as the body's main fuel reserve. Acetyl-CoA formed by β-oxidation may undergo three fates : (i) It is oxidised to $CO_2 + H_2O$ *via* the Citric acid cycle (ii) It is the precursor for synthesis of cholesterol and other steroids (iii) In the liver, it is used to form **ketone bodies** (acetoacetate and 3- hydroxybutyrate) that are important fuels in prolonged fasting.
- The non-essential amino acids, which are supplied in the diet can also be formed from metabolic intermediates by **transamination** using the amino nitrogen from other amino acids. After deamination, amino nitrogen is excreted as urea, and the carbon skeletons that remain after transamination may : (i) be oxidised to CO_2 *via* the Citric acid cycle (ii) be used to synthesise glucose **(gluconeogenesis),** or (iii) form ketone bodies, which may be oxidised or be used for synthesis of fatty acids.

Integration of metabolic pathways at tissue and organ level

- At tissue and organ level, the nature of substrates entering and metabolites leaving tissues and organs is defined.
- Amino acids and glucose resulting from digestion of proteins and carbohydrates, respectively are absorbed *via* hepatic portal vein.
- Excess glucose is converted to glycogen **(glycogenesis)** or to fatty acids **(lipogenesis)** in liver.
- In between the meals, glycogen is broken down to glucose **(glycogenolysis)** and non-carbohydrate metabolites (lactate, glycerol, etc.) are converted to glucose **(gluconeogenesis)** in liver.
- Liver synthesises major plasma proteins and deaminates amino acids that are in excess, forming urea which is transported to kidney and excreted.
- Skeletal muscles utilise glucose both aerobically forming CO_2 and anaerobically forming lactate.
- Lipids in the diet are hydrolysed to **monoacylglycerols** and fatty acids in the gut, packaged with protein and secreted into the lymphatic system and thence into the bloodstream as **chylomicrons.** It is first metabolised by tissues that have **lipoprotein lipase**, which hydrolyses the triacylglycerol, releasing fatty acids.
- The other major source of long-chain fatty acids is synthesis from carbohydrate **(lipogenesis)** in adipose tissue and the liver.
- Adipose tissue triacylglycerol is hydrolysed **(lipolysis)** and the fatty acids are transported, bound to serum albumin; they are taken up by most tissues (but not brain or erythrocytes) and either esterified to triacylglycerols for storage or oxidised as a fuel.
- In the liver, triacylglycerol arising from lipogenesis, free fatty acids and chylomicron remnants are secreted into the circulation in **very low density lipoprotein (VLDL)**. This triacylglycerol undergoes a fate similar to that of chylomicrons.
- Partial oxidation of fatty acids in the liver leads to ketone body production **(ketogenesis)**.





Integration of metabolic pathways at sub-cellular level

- Each cell organelle, (*e.g.,* mitochondrion) or compartment (*e.g.,* cytosol) has specific roles that form part of the sub-cellular pattern of metabolic pathways.
- Compartmentation of pathways in separate sub-cellular compartments or organelles permits integration and regulation of metabolism. There is central role of the **mitochondrion**, since it acts as the focus of carbohydrate, lipid, and amino acid metabolism. It contains **the respiratory chain** and **ATP synthase** as well as the **enzymes of the Citric acid cycle, β-oxidation of fatty acids** and **ketogenesis.**
- Glycolysis, the pentose phosphate pathway, and fatty acid synthesis all occur in the cytosol. In gluconeogenesis, substrates such as lactate and pyruvate, which are formed in the cytosol, enter the mitochondrion to yield **oxaloacetate** as a precursor for the synthesis of glucose in the cytosol.
- The membranes of the endoplasmic reticulum contain the enzyme system for triacylglycerol synthesis, and the ribosomes, are responsible for protein synthesis.

CONCEPT MAP

HUMAN HEART : STRUCTURE AND FUNCTION

Human heart is a hollow, four chambered, fibro-muscular organ of somewhat conical or pyramidal shape having upper broad base and lower narrow apex. Apex is slightly directed towards the left.

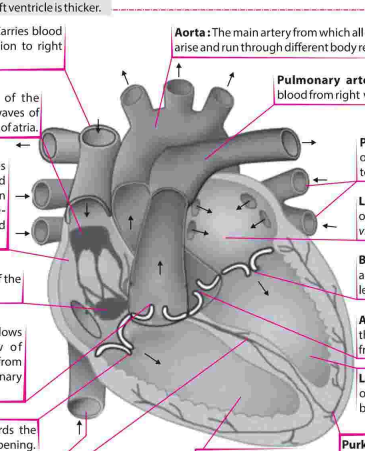
Structure of Heart

- Entire heart is enclosed by a double layered sac called **pericardium**. In between the two layers, **pericardial cavity** is present. It normally contains 5-30 mL of **pericardial fluid** which lubricates the heart, permits it to contract with minimal friction and protects the heart from external injury.

Internally, heart contains four chambers *i.e.*, two thin walled **atria** separated from each other by interatrial septum and two thick walled **ventricles** separated from each other by interventricular septum. Of the two ventricles, left ventricle is thicker.

Location and Size

- Heart is located between the lungs in the thoracic cavity. An average adult heart is about 12 cm.
- It weighs around 280-340 gms (in an average male) and 230-280 gms (in an average female).



Superior vena cava : Carries blood from body's upper region to right atrium.

SA node: Pacemaker of the heart, which spreads waves of contraction across walls of atria.

Right atrium : It receives deoxygenated blood from systemic circulation *via* superior and inferior venae cavae and coronary sinus.

AV node : Pacesetter of the heart.

Pulmonary valve : Allows unidirectional flow of deoxygenated blood from right ventricle to pulmonary artery.

Tricuspid valve : Guards the right atrio-ventricular opening.

Inferior vena cava: Carries blood from body's lower region to the heart.

Bundle of His: Mass of specialised fibres, originating from AV node.

Aorta : The main artery from which all other arteries arise and run through different body regions.

Pulmonary artery: Carries deoxygenated blood from right ventricle to lungs.

Pulmonary veins : Carry oxygenated blood from lungs to left atrium.

Left atrium : It receives oxygenated blood from lungs *via* pulmonary veins.

Bicuspid valve : Also known as **mitral** valve. It guards the left atrio -ventricular opening.

Aortic valve : It is situated at the aortic orifice which leads from left ventricle to the aorta.

Left ventricle : It supplies oxygenated blood to different body tissues.

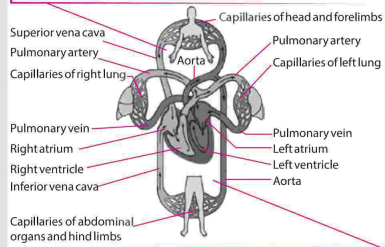
Right ventricle : It supplies deoxygenated blood to the lungs *via* pulmonary artery for oxygenation.

Purkinje fibres: Network of fine fibres, formed by division of Bundle of His. Bundle of His and Purkinje fibres convey impulse of contraction from AV node to the myocardium of the ventricles.

Function of Heart

Function of heart is to pump blood throughout the body *via* the circulatory system supplying oxygen and nutrients to the tissues and removing carbon dioxide and other wastes from the same. The heart circulates the blood through two pathways (**double circulation**) *i.e.*, pulmonary and systemic circuits. It checks mixing of blood.

In **pulmonary circuit**, deoxygenated blood flows from right ventricle to the lungs and oxygenated blood returns from lungs to the left atrium.



In **systemic circuit**, oxygenated blood leaves the body from the left ventricle *via* aorta and from there it enters arteries and capillaries which supply the body's tissue with oxygen. Deoxygenated blood returns *via* veins to the venae cavae, re-entering the heart's right atrium.

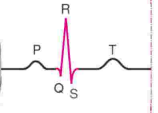
Cardiac Cycle

Cardiac cycle consist of one cycle of contraction and relaxation of cardiac muscles.

Contraction of atria stimulated by SA node, forces blood into the relaxed ventricles.

The tricuspid and bicuspid valves open when the pressure in the ventricles falls and blood flows from the atria into the ventricles. Contraction of the heart does not cause this blood flow. It is due to the fact that the pressure within the relaxed ventricles is less than that in the atria and veins.

The ventricles begin to contract due to a wave of contraction, stimulated by the AV node. The bicuspid and tricuspid valves close immediately producing part of the **first heart sound**.



As ventricular pressure rises and exceeds pressure in the arteries, the semilunar valves open and blood is ejected into pulmonary trunks and aorta.

As ventricles relax, pressure in ventricles drops, blood flows back against cusps of semilunar valves and forces them to close. This causes the **second heart sound**. Blood flows into the relaxed atria.

CONCEPT MAP

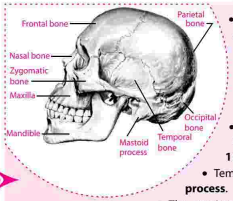
HUMAN SKELETON

Human skeleton constitutes the rigid framework of connected bones that gives shape to the body, protects and supports its soft organs and tissues and provides attachments for muscles. Human skeleton is made up of 206 bones (300 bones in newborns) which are distributed into axial and appendicular skeleton.

AXIAL SKELETON

- It lies along the longitudinal axis of the body; supports and protects the organs of the head, neck and trunk.
- It includes **skull, vertebral column, sternum** and **ribs**.

SKULL

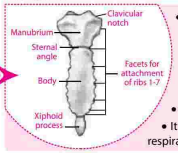


- Skull is the bony framework of the head.
- It consists of **29 bones**, separated by sutures. These bones are **cranial bones** (8 flattened bones forming the brain box or **cranium**), **facial bones** (14 bones forming the front part of the skull), **hyoid bone** (single bone forming floor of the buccal cavity) and **bones of middle ear** (3 small bones in each ear, namely **malleus**, **incus** and **stapes**).
- The bones of cranium are : **1 frontal** bone, **2 parietal** bones, **2 temporal** bones, **1 occipital** bone, **1 sphenoid** bone and **1 ethmoid** bone.
- Temporal bone has a projection called **mastoid process**.
- The cranium has two small protuberances at the posterior end called **occipital condyles**, that articulate with the **first vertebra** (atlas vertebra), thus, human skull is dicondylic.
- 14 bones form the skeleton of face *viz.* **2 zygomatic, 2 maxilla, 2 nasal, 2 lacrimal, 1 vomer, 2 palatine, 2 inferior nasal conchae** and **1 mandible**.
- **Hyoid** is a u-shaped bone which attaches tongue with the floor of buccal cavity. It does not articulate with any other bone.
- A large hole called **foramen magnum** at the base of skull allows the brain to continue into the spinal cord located in the backbone.
- Skull protects our brain; it bears jaws which help in mastication of food, etc.

VERTEBRAL COLUMN

- It is also called **backbone** or **spine**. It is curved, vertical rod, about **70 cm long**, in the mid-dorsal line of the neck and trunk. It consists of **33 vertebrae**. However it consists of 26 bones, because five sacral vertebrae are fused to form one sacrum and four coccygeal vertebrae are fused to form one coccyx.
- A typical vertebra has a large, disc-like anterior, flattened portion, the **centrum** or **body** and a posterior portion, the **neural arch**. The latter encloses the spinal cord. The hole formed by the neural arch is the **vertebral foramen**. The vertebral foramina of all twenty four vertebrae form the **vertebral canal** or **neural canal**.
- Vertebrae are categorised into five groups: **cervical (7)**, **thoracic (12)**, **lumbar (5)**, **sacral (5)** and **coccygeal (4)**.
- Vertebral column displays four curves to enhance balancing powers and firmness for upright posture of the body. These curvatures are cervical, thoracic, lumbar and pelvic (=sacral).
- Between the centre of adjacent vertebrae there are elastic pads of fibrocartilage, the **intervertebral discs** which provide mobility to the vertebrae, check undue frictions and take up shocks.
- Vertebral column carries the weight of the body in motion and when the organism is standing.

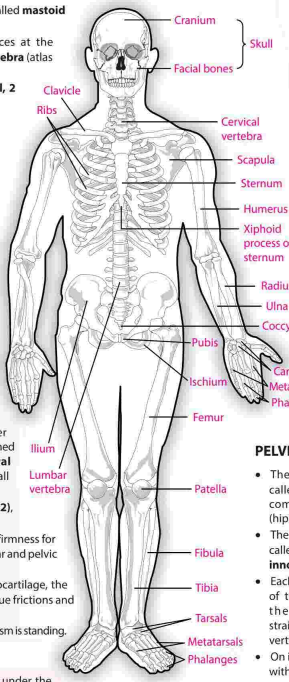
STERNUM



- This is a flat bone which is present just under the skin in the middle of the front of the chest. It is about 15 cm long.
- Its shape is like a dagger and consists of three parts—the **manubrium** is the uppermost part, the **body** is the middle portion and the **xiphoid process** is the tip of the bone.
- The true ribs (7 pairs) are attached to the sternum.
- It protects the internal organs in the thoracic region and helps in the respiratory mechanism.

RIBS

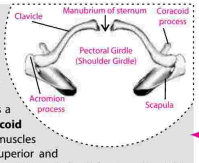
- The **ribs** are thin, flat, curved bones that form a protective cage around the organs in the upper body.
- Ribs comprise of **24 bones arranged in 12 pairs**. Each rib remains attached to the respective thoracic vertebra.
- The **first seven pairs of ribs** are attached directly with the sternum and are called **true ribs**. The **8th, 9th** and **10th** pairs of ribs do not articulate directly with sternum, but join the seventh rib by hyaline cartilage. These are called **vertebrochondral ribs** or **false ribs**. The last two (**11th** and **12th**) pairs of ribs remain free anteriorly and are not attached either to sternum or cartilage of another rib, and are called **floating ribs**.
- A typical rib consists of 2 parts : **vertebral** and **sternal**. The vertebral part is long and bony. It articulates with the thoracic vertebrae.
- The sternal part is short and cartilaginous. It articulates with the sternum or sternal part of its upper rib.



APPENDICULAR SKELETON

- It is situated at the lateral sides which actually extend outwards from the principal axis.
- It consists of two girdles, the **pectoral** and **pelvic girdles** and the **bones of arms** and **legs**.

PECTORAL GIRDLE

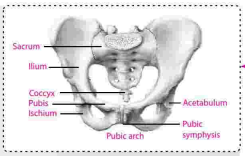


- Each pectoral girdle consists of two bones : **1 clavicle** and **1 scapula**. The scapula (shoulder blade) consists of a sharp ridge, the **spine** and a triangular **body**. The end of the spine projects as a flattened and expanded process called **acromion**. This process articulates with the clavicle.
- At the lateral end of the superior of the scapula is a projection of the anterior surface called the **coracoid process**, to which the tendons of the muscles attach. At the point where the superior and lateral borders of the scapula meet there is the lateral angle which presents a shallow articular surface termed as **glenoid cavity** into which the head of the humerus is articulated.
- The primary function of the pectoral girdle is to provide an attachment point for the numerous muscles that allow the shoulder and elbow joints to move.

FORELIMBS

- Each arm has **30 bones**, which constitute **1 humerus** (upper arm), **1 radius** and **1 ulna** (lower arm), **8 carpals** (wrist), **5 metacarpals** (palm) and **14 phalanges** (digits).
- The **humerus is the longest bone in the upper extremity**.
- At the bottom of the humerus, are two depressions where it connects to the ulna and radius of the forearm.
- Together, the humerus and the ulna make up the elbow, ulna is longer than the radius. Radius, however, contributes more to the movement of the wrist and hand than the ulna.
  - Each wrist is composed of **eight carpals** which are arranged in two rows : **scaphoid, lunate, triquetrum** and **pisiform** in proximal row and **trapezium, trapezoid, capitate** and **hamate** in distal row.
- The forelimbs give support to the shoulders by articulating the head of the humerus with the glenoid cavity of the pectoral girdle.

PELVIC GIRDLE



- The **pelvic girdle**, also called the **hip girdle**, is composed of two coxal (hip) bones.
- The **coxal bones** are also called the **ossa coxae** or **innominate** bones.
- Each coxal bone consists of three separate parts : the **ilium** (short and straight bone), the **ischium** (lower elongated bone, running parallel to vertebral column) and the **pubis** (inner, smaller bone).
- On its outer surface it has a deep depression called the **acetabulum** which, with almost spherical head of the femur, forms the hip joint.
- It supports the weight of the body from the vertebral column. It also protects and supports the lower organs, including the urinary bladder, the reproductive organs, and the developing foetus in case of a pregnant woman.

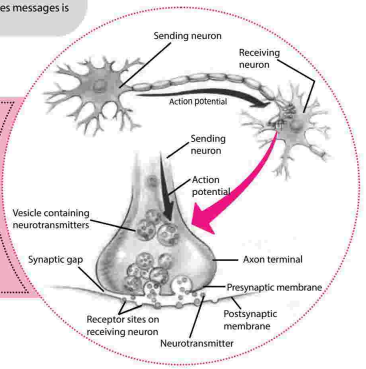
HINDLIMBS

- Each leg has **30 bones** which constitute **1 femur, 1 patella, 1 tibia, 1 fibula, 7 tarsals, 5 metatarsals** and **14 phalanges**.
- **Femur, tibia** and **fibula** bones together support the shank of the leg. The **tarsals** form the ankle, **metatarsals** form the sole and **phalanges** form the digits of the foot.
- The **femur** is the **longest, largest**, and **strongest bone** in the body whose head fits into the acetabulum of hip girdle.
- The **tibia** connects to the femur to form the knee joint and with the talus, a foot bone, to allow the ankle to flex and extend.
- The **tibia is larger than the fibula** because it bears most of the weight, while the fibula serves as an area for muscle attachment.
- **Fibula** is shorter, thinner and slender.
- Each ankle is composed of seven **tarsals** which are **calcaneum, talus, cuboid, navicular** and **first, second, third cuneiforms**.
- The leg bones carry the weight of the body and are involved in propulsion and support.

CONCEPT MAP

SYNAPSE

Synapse is an anatomically specialised junction between two neurons, where the axon (or some other portion) of one cell (neuron) terminates on the dendrites or some other portion of another cell. The term 'synapse' was first introduced by Charles Sherrington (1924). Transmission of nerve impulse takes place across a synapse between neurons or neurons and an effector. The neuron which sends messages is called presynaptic cell whereas the neuron which receives messages is postsynaptic neuron.



STRUCTURE OF SYNAPSE

Most of the synapses comprise the following structures:

(i) **Synaptic knob** – Terminal bulbous ending of presynaptic axon which is devoid of neurofilaments but its cytoplasm contains:

(a) **Synaptic vesicles** – Small vesicles present in presynaptic cytoplasm that contain neurotransmitters (for excitation or inhibition), like acetylcholine, GABA, etc.

(b) **Mitochondria, ER** and **microtubules**.

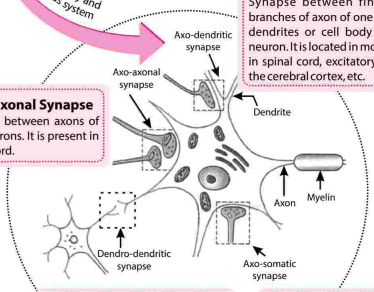
(c) **Presynaptic membrane** – Nerve membrane which is in close approximation with membrane of postsynaptic cell.

(ii) **Sub-synaptic and postsynaptic membrane** – The surface of the cell membrane involved in the synapse is called the sub-synaptic membrane and the remaining of the motor neuron cell membrane is called the postsynaptic membrane. Receptor sites for neurotransmitters are usually located on the sub-synaptic membrane.

TYPES OF SYNAPSE

On the basis of proximity and location within nervous system

On the basis of physiology



Axo-dendritic Synapse

Synapse between fine terminal branches of axon of one neuron and dendrites or cell body of another neuron. It is located in motor neurons in spinal cord, excitatory synapse in the cerebral cortex, etc.

Axo-axonal Synapse

Synapse between axons of two neurons. It is present in spinal cord.

Dendro-dendritic Synapse

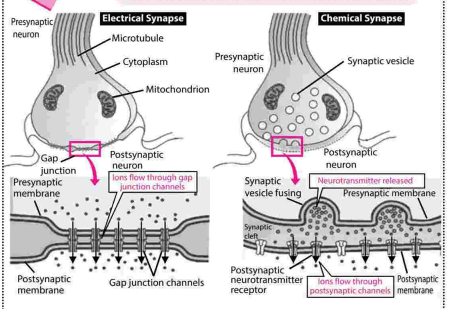
- Synapse between dendrites of two neurons, but is rare. It is present between mitral and granule cell in the bulb.

Axo-somatic Synapse

Synapse between axon of one neuron and soma of another neuron. It is present in motor neurons in spinal cord and autonomic ganglia.

Chemical Synapse

- Signals are transmitted across synaptic cleft in form of chemical messenger – a neurotransmitter, released from presynaptic axon terminal.
- Chemical synapse operates only in one direction, as neurotransmitter is stored on the presynaptic side of synaptic cleft, whereas receptors for neuro-transmitters are on postsynaptic side.



Electrical Synapse

- Here pre-and postsynaptic membrane are joined by gap junctions, through which ions can pass easily.
- Impulse transmission across electrical synapse is faster than chemical synapse because of the direct flow of electrical current from one neuron to another through gap junction,

MECHANISM OF IMPULSE CONDUCTION

At Chemical Synapse

Mechanism of chemical transmission across a synapse is as follows:

Action potential arrives at axon terminal

▼

Voltage gated Ca^{2+} ion channels open and electrochemical gradient favours influx of Ca^{2+} and Ca^{2+} flows into axon terminal

▼

Ca^{2+} ions cause synaptic vesicles to move to the surface of the knob and fuse with synaptic membrane terminal

▼

Vesicles release neurotransmitters by exocytosis

▼

Neurotransmitters diffuse across synaptic cleft and bind to receptors on postsynaptic membrane

▼

This causes depolarisation and generation of action potential in the postsynaptic membrane.

At Electrical Synapse

- Gap junctions in electrical synapse allow the local currents resulting from arriving action potentials to flow directly across the junction from one neuron to the other.
- This depolarises the membrane of the second neuron to threshold, continuing the propagation of the action potential.

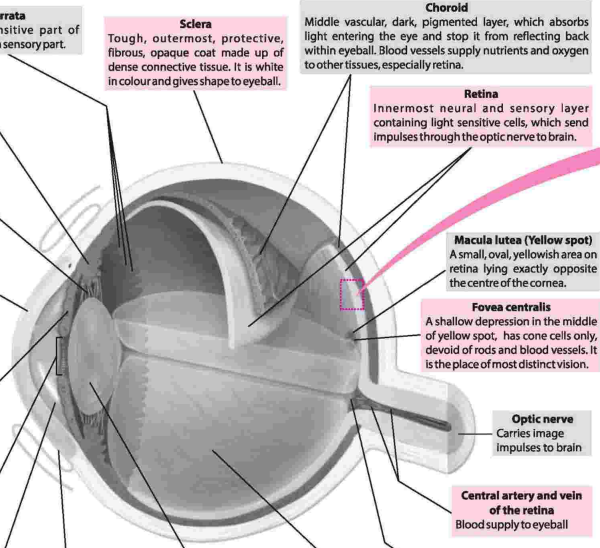
PROPERTIES OF SYNAPSE

- **Convergence and Divergence :** Many presynaptic neurons **converge** on any single postsynaptic neuron, *e.g.,* in spinal motor neurons, some inputs come from dorsal root, some from long descending spinal tracts and many from interconnecting neurons. The axons of most presynaptic neurons divide into many branches that **diverge** to end on many postsynaptic neurons.
- **Fatigue :** Repeated stimulation of presynaptic neuron leads to gradual decrease and finally disappearance of the postsynaptic response. This is due to exhaustion of chemical transmitter, as its synthesis is not as rapid as the release.
- **Synaptic Delay :** When an impulse reaches the presynaptic terminal, there is a gap of about 0.5 msec., before a response is obtained in postsynaptic neuron. This is due to the time taken by synaptic mediator to be released and to act on postsynaptic membrane.
- **Synaptic Plasticity :** Plasticity implies the capability of being easily moulded or changed. Synaptic conduction thus can be increased or decreased on the basis of past experience. These changes can be presynaptic or postsynaptic in location and play an important role in learning and memory.

CONCEPT MAP

THE EYE

The eye is a special organ of the sense of sight, an extension of human brain which permits humans to connect with the outside world. The adult human eyeball is hollow, spherical structure, situated in the orbital cavity. Only 1/6th of the eyeball is visible outside.



Ora serrata
Demarcates sensitive part of retina from its non sensory part.

Sclera
Tough, outermost, protective, fibrous, opaque coat made up of dense connective tissue. It is white in colour and gives shape to eyeball.

Choroid
Middle vascular, dark, pigmented layer, which absorbs light entering the eye and stop it from reflecting back within eyeball. Blood vessels supply nutrients and oxygen to other tissues, especially retina.

Ciliary body
Made up of smooth muscle, changes the shape of the lens depending upon distance of object to bring images into focus.

Retina
Innermost neural and sensory layer containing light sensitive cells, which send impulses through the optic nerve to brain.

Ciliary zonule (Suspensory ligament)
Holds the lens in place and connects it to the ciliary muscles.

Cornea
Anterior clear area of the sclera, which admits and focuses light into eyeball. The cornea is avascular and absorbs oxygen from the air.

Macula lutea (Yellow spot)
A small, oval, yellowish area on retina lying exactly opposite the centre of the cornea.

Fovea centralis
A shallow depression in the middle of yellow spot, has cone cells only, devoid of rods and blood vessels. It is the place of most distinct vision.

Iris
Pigmented, opaque, muscular structure of eye, which gives colour to the eye and regulates intensity of light entering the eye either by constriction or dilation of pupil.

Optic nerve
Carries image impulses to brain

Pupil
A hole in the centre of the iris, through which light enters the eye. Pupil dilates in dark to permit more light in and contracts in bright light to reduce light falling in.

Central artery and vein of the retina
Blood supply to eyeball

Blind spot
Point where optic nerve leaves the eyeball, devoid of light sensitive cells to detect image.

Aqueous humor
Watery liquid, formed by capillaries of ciliary processes, that fills space between the cornea and lens. It provides nutrition to avascular structures of the eye, *i.e.,* cornea and lens and maintains intraocular pressure and helps in image forming mechanisms.

Conjunctiva
Thin, clear, protective front layer over the surface of the eye and lining the eyelids. An infection of eye called conjunctivitis occurs here.

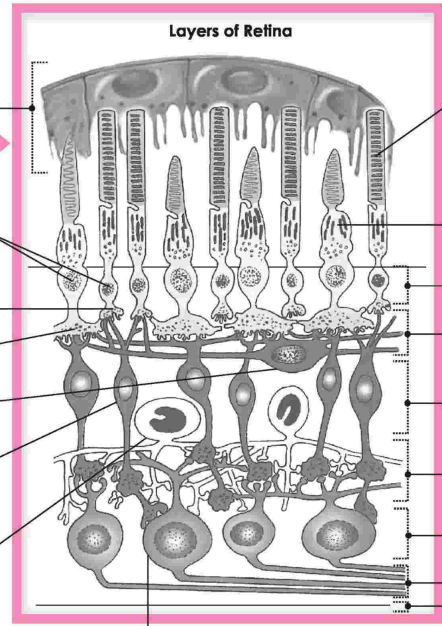
Lens
Transparent, biconvex, circular body lying immediately behind pupil. It forms image on retina. It separates aqueous and vitreous humors.

Vitreous humor
Clear jelly-like fluid that fills space between the lens and retina, which helps to maintain the shape and inner pressure of eyeball. It allows undistorted light to fall on retina.

Pigmented epithelium
It contains melanin pigment which along with the pigmented choroid absorbs light and prevents the reflection of rays back within eyeball which may distort the image formation.

External limiting membrane
Formed by the glial tissues, it is the continuation of internal limiting membrane and is pierced by the rods and cones.

Outer nuclear layer
Formed by the cell bodies and nuclei of rods and cones.



Rods
Contain photosensitive pigment rhodopsin. The rods mainly enable to see in darkness, therefore are present in large numbers in nocturnal animals.

Cones
Contain photosensitive pigment photopsin, involved in colour vision.

Outer plexiform layer
Axons of rods and cones synapse here with dendrites of bipolar cells and horizontal cell processes.

Inner nuclear layer
Contains cell bodies and nuclei of bipolar, neurons, horizontal neurons and amacrine cells.

Horizontal cell
Connect one receptor cell to another receptor cell.

Amacrine cell
Processes make synaptic contacts with dendrites of both ganglion and bipolar cells and connect ganglion cells to one another.

Ganglion cell
It gives rise to optic nerve fibres and sends impulses to brain.

Inner limiting membrane
It separates the retina from the vitreous humor. It is formed by the glial tissues.

Optic nerve fibres
Formed by joining the axon of ganglion cells; here all the axons run parallel.

Ganglion cell layer
A single layer of cell containing cell bodies of ganglion cells.

Inner plexiform layer
It is the site of major processing of the visual image. Axons of bipolar and Amacrine cell synapse with the dendrites of ganglion cells.

Mechanism of Vision

Light from object pass through cornea, aqueous humor, lens and vitreous humor. → Light is focussed on retina, where it is converted into potentials in rods and cones. → Light induces dissociation of retinene from opsin which activates transducin, thereby causing potential generation. → Potential generated in photoreceptor cells triggers action potential in ganglion cells. → Action potential transmitted by optic nerve to visual area of the brain. → Neural impulses are analysed and erect image is recognised.

CONCEPT MAP

THE EAR

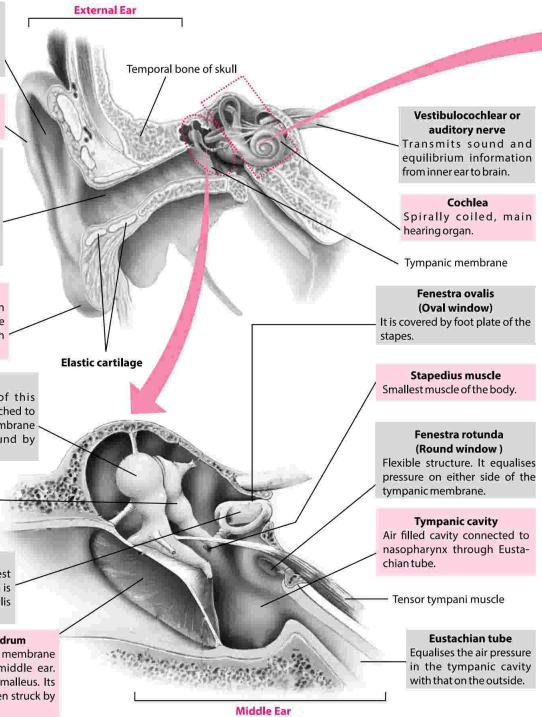
Ears are a pair of sense organs that are situated on the either sides of the head to produce a sensation of hearing and to maintain body's equilibrium and balance. Anatomically, human ear is divided into three regions - external ear, middle ear and inner ear.

Pinna (Auricle)
It is a cartilaginous structure which help to amplify (detect) and direct the sound waves towards auditory canal.

Helix
The outer prominent ridge of auricle.

External acoustic meatus
It is a tubular passage supported by cartilage in its external part and by bone in the inner part. Internally it is lined by stratified epithelium and ceruminous gland that secretes cerumen (ear wax).

Lobule
It is a soft, pliable flap of skin composed of fibrous and adipose tissue. It is richly supplied with blood capillaries.



Vestibulocochlear or auditory nerve
Transmits sound and equilibrium information from inner ear to brain.

Cochlea
Spirally coiled, main hearing organ.

Tympanic membrane

Fenestra ovalis (Oval window)
It is covered by foot plate of the stapes.

Stapedius muscle
Smallest muscle of the body.

Fenestra rotunda (Round window)
Flexible structure. It equalises pressure on either side of the tympanic membrane.

Tympanic cavity
Air filled cavity connected to nasopharynx through Eustachian tube.

Tensor tympani muscle

Eustachian tube
Equalises the air pressure in the tympanic cavity with that on the outside.

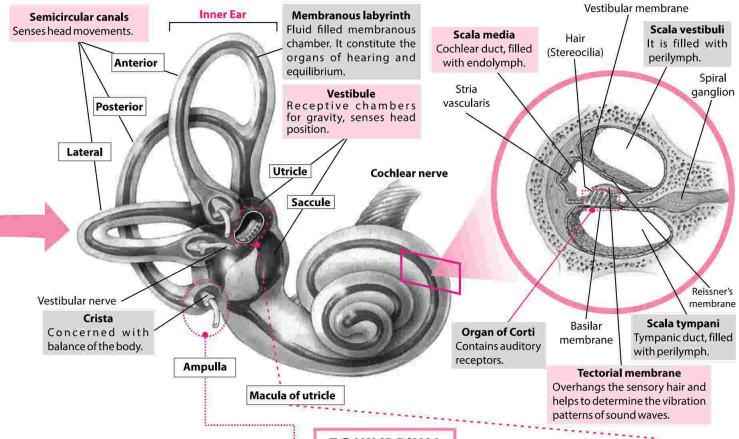
Ear ossicles

Malleus
Largest ossicle. Handle of this hammer shaped bone is attached to inner side of tympanic membrane and its head is firmly bound by ligaments to incus.

Incus
Middle, anvil shaped bone. It is connected to malleus on one side and the stapes on other.

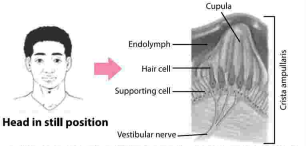
Stapes
Smallest ossicle and smallest bone of the human body. It is attached to the fenestra ovalis (oval window).

Tympanic membrane/ Eardrum
Oval, thin and semi-transparent membrane that separates external and middle ear. Internally it is attached to the malleus. Its central part umbo, vibrates when struck by sound waves.



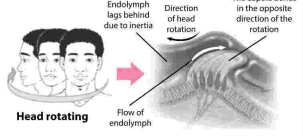
EQUILIBRIUM

Rotational Movement



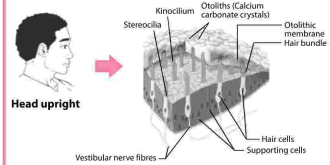
Head in still position

- The base of each semicircular canal where it meets vestibule, connects to a region called ampulla. The ampulla contains hair cells that respond to rotational movement of the head.
- The fluid in each canal will move slowly in the direction of motion of cupula bending the stereocilia within it.
- When the head rotates, the fluid (endolymph) inside the semicircular canals pushes against the cupula and causes the cilia and cupula to bend opposite to direction of head rotation.
- This bending either depolarise or hyperpolarise the hair cells depending on the direction in which they are bent. This stimulates the production of action potential in associated neurons to maintain balance and equilibrium.



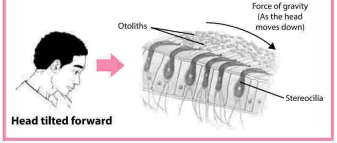
Head rotating

Linear Movement



Head upright

- Utricle and saccule are parts of balancing apparatus that detect linear accelerations. The hairlike processes called stereocilia are embedded within a gelatinous membrane containing calcium carbonate crystals (otoliths).
- The utricle is more sensitive to horizontal acceleration (as in a moving car) and the saccule to vertical acceleration (as in an elevator).
- When the head moves forward or tilts, otoliths move forward slowly and the inertia bends the stereocilia on the hair cells and depolarise them. Electrical signals are sent to the brain which interprets the signals.
- Brain sends impulses to muscle to regain normal condition.



Head tilted forward

MECHANISM OF HEARING

Sound waves are collected from an external source by the help of ear pinna and are transmitted to tympanic membrane through an external auditory meatus. → Tympanic membrane (eardrum) stretches; and as the air molecules push the membrane, they cause it to vibrate at the same frequency as the sound wave. → Tympanic membrane bows inwards and transmits the sound waves to the ear ossicles. → Perilymph of inner ear receives the vibrations through fenestra ovalis. → Vibrations are further transferred to scala vestibuli and then to scala media through Reissner's membrane of cochlea. → Movements in fluid (endolymph) of scala media and tectorial membrane stimulate the sensory hair of the organ of Corti. → Hair cells receive the impulses and transmit it to brain through auditory nerve and finally sound is detected by the brain.

CONCEPT MAP

ASEXUAL REPRODUCTION

Life cannot be created *de novo* rather it arises from pre-existing life. Reproduction is the only method by which continuity of life is maintained. It is of two types: asexual and sexual. Asexual reproduction is the formation of new individual without involving fusion of gametes. It is uniparental as offspring are produced by a single parent.

Fission

- It is a type of asexual reproduction in which the parent organism divides into two or more daughter cells.
- In this type of reproduction, whole parent body acts as the reproductive unit.
- It is of three types:

(a) Binary fission : In this, parent organism divides into two halves, each half forming an independent daughter organism. It can be simple (occurs through any plane, *e.g., Amoeba*), longitudinal (plane of division is longitudinal axis of body, *e.g., Euglena*), transverse (plane of division runs along transverse axis of body, *e.g., Paramecium*) and oblique (plane of division is oblique, *e.g., Ceratium*).

(b) Multiple fission : In this process, parent body divides into many similar daughter organisms. It occurs during unfavourable conditions. Nucleus of the parent divides by repeated amitosis into many nuclei which eventually form several daughter cells. *E.g., Amoeba, Plasmodium* (malarial parasite).

(c) Plasmotomy-Division of multinucleate parent into many multinucleate daughter individuals without division of nuclei. Nuclear division occurs later to maintain number of nuclei. *E.g., Opalina, Pelomyxa.*

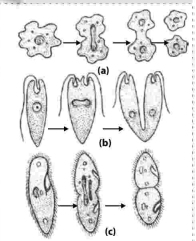


Fig.: Binary fission in (a) *Amoeba* (b) *Euglena* (c) *Paramecium*

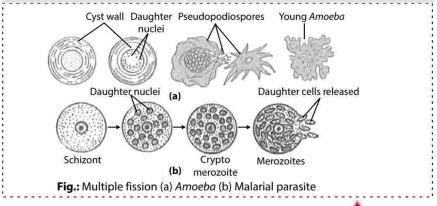


Fig.: Multiple fission (a) *Amoeba* (b) Malarial parasite

CHARACTERISTICS OF ASEXUAL REPRODUCTION

- It is more primitive than sexual reproduction as it involves only mitotic divisions.
- New organisms are produced from the somatic part of parental organism, so it is also called as somatogenic reproduction.
- New individuals produced are genetically similar to the parent as well as to each other and are called clones. Hence, it plays no role in evolution.
- Unit of reproduction may be either whole parent body, or a bud, or a body fragment, or a single somatic cell.
- It is usually found in lower organisms like protistan protozoans (*Amoeba, Paramecium*), sponges (*Scypha*), coelenterates, (*Hydra, Tubularia,* etc.), certain flatworms (*Planaria*), some worms and tunicates (*Salpa, Ascidia*, etc.). It is absent in higher invertebrates and all vertebrates.

Regeneration

- It refers to the growth of new tissues or organs to replace lost or damaged part.
- Regeneration is of two types: **morphallaxis** (formation of whole body from a fragment) and **epimorphosis** (replacement of lost parts). It can be reparative (regeneration of damaged tissue only) or restorative (redevelopment of severed body part). In epimorphosis, a mass of undifferentiated cell referred to as blastema is formed after wound healing and then the blastema cells actively proliferate to restore the lost part of the amputated organ.
- Regeneration is found in *Hydra*, starfish, *Planaria*, etc.

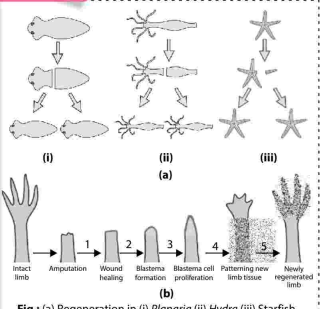


Fig.: (a) Regeneration in (i) *Planaria* (ii) *Hydra* (iii) Starfish (b) Epimorphosis

TYPES OF ASEXUAL REPRODUCTION

Budding

- Budding refers to the process of formation of daughter individuals from a small projection or bud arising on the parent body.
- Each bud enlarges, develops parental characters and separates to lead an independent life.
- Budding can be either **exogenous** (formed on the outer surface) *e.g., Hydra*, yeast or **endogenous** (formed inside parent body) *e.g., Spongilla.* In *Spongilla*, bud is called a **gemmule.**

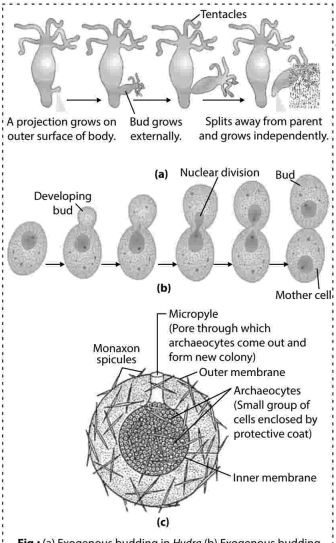


Fig.: (a) Exogenous budding in *Hydra* (b) Exogenous budding in yeast (c) Endogenous budding (gemmule) in *Spongilla*

Fragmentation

- In this type of reproduction, parent body breaks into two or more pieces called fragments.
- Each fragment develops into a new organism.
- In fragmentation, rate of reproduction is high.
- It occurs in flatworms, sea anemones, coelenterates, echinoderms, algae like *Spirogyra*, etc.

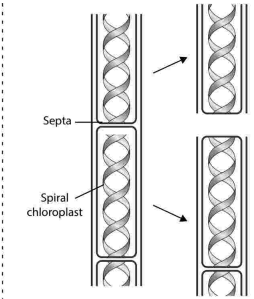


Fig.: Fragmentation in *Spirogyra*

Sporulation

- Spores are minute, single celled, thin or thick walled propagules which are dispersive structures released from the parent body and form new individuals. Spore formation is common in members of monera, protista, algae and fungi. Some of the commonly produced spores are:

(a) Zoospores : Motile and flagellated spores produced inside zoosporangia. Flagella help in proper dispersal in aquatic habitat. *E.g.*, algae and lower fungi like Phycomycetes.

(b) Conidia : Non-motile spores produced singly or in chains by constriction at the tip or lateral side of special hyphal branches called conidiophores. These are dispersed by wind and germinate to form new individuals. *E.g., Penicillium.*

(c) Chlamydospores : Thick walled spores produced directly from hyphal cells. May be terminal or intercalary in position and capable of withstanding unfavourable conditions. *E.g., Rhizopus.*

(d) Oidia : Small fragments of hyphae that are thin walled and do not store reserve food material. Oidia give rise to new hyphae. These are formed under conditions of excess water, sugar and certain salts. *E.g., Agaricus.*

(e) Sporangiospores : Non-motile spores produced inside sporangia. Usually get dispersed by wind and germinate to form new mycelium. *E.g., Rhizopus, Mucor.*

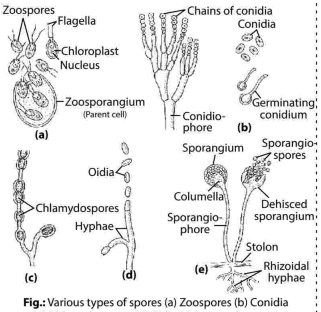


Fig.: Various types of spores (a) Zoospores (b) Conidia (c) Chlamydospores (d) Oidia (e) Sporangiospores

CONCEPT MAP

ASEXUAL REPRODUCTION

Asexual reproduction is the production of offspring from a single parent with or without the involvement of gamete formation. The offspring produced are morphologically and genetically similar to one another and are exact copies of their parents, hence called clones.

Binary fission

The parent organism divides mitotically into two halves, each half forming an independent daughter organism. It is of following types: (i) **Simple binary fission** - division occurs through any plane, *e.g. Amoeba*. (ii) **Longitudinal binary fission** - division passes along the longitudinal axis of an organism, *e.g., Euglena*. (iii) **Transverse binary fission** - division occurs along the transverse axis of the individual, *e.g., Planaria*. (iv) **Oblique binary fission** - division is oblique, *e.g., Ceratium*.

Plasmotomy

There is division of a multinucleate parent into many multinucleate daughter individuals without division of nuclei, *e.g., Opalina*.

FISSION

It is the division of parent body into 2 or more daughter individuals identical to the parent. It is of three types: binary fission, multiple fission and plasmotomy.

Multiple fission

There is repeated division of the parent body into many daughter organisms, *e.g., Plasmodium*.

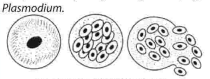


Fig.: Multiple fission in *Plasmodium*

BUDDING

Daughter individual is formed from a small part or bud, arising from parent body. In animals it is of three types:

(i) **Exogenous budding** : The bud grows externally on the surface of the body. It may split away from the parent *e.g., Hydra* or remain attached to it, *e.g., Sycon*. In yeast, bud is formed on one side of the parent cell and soon it separates and grows into a new individual.

(ii) **Endogenous budding** : The buds are formed within the parent's body. They are called gemmules which consist of small group of cells in a protective covering, *e.g., Spongilla*.

(iii) **Strobilation :** The repeated formation of similar segments by a process of budding is called strobilation. The segmented body is called a **strobila** larva and each segment is called an **ephyra** larva *e.g., Aurelia*.

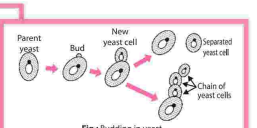


Fig.: Budding in yeast

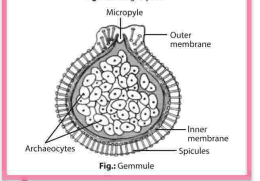


Fig.: Gemmule

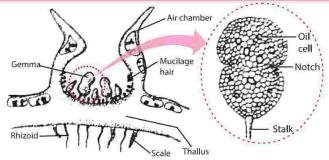


Fig.: Gemma cup of *Marchantia*

GEMMAE

These are unicellular or multicellular propagules which develop in small receptacles called gemma cups. They detach from the parent and grow into new individuals, *e.g., Marchantia*.

FRAGMENTATION

The parent body breaks into two or more pieces called fragments. Each fragment develops into an individual, *e.g., Spirogyra, Rhizopus* etc.

SPORE FORMATION

Spores are microscopic, single-celled, thin or thick walled propagules which develop asexually on the parent body. Spores can be of various types *viz.* **zoospores** (motile and flagellated, *e.g., Chlamydomonas*), **conidia** (non-motile and produced exogenously *e.g., Penicillium*), **chlamydospores** (thick-walled and non-motile *e.g., Rhizopus*), **oidia** (small, thin-walled fragments, *e.g., Agaricus*) and **sporangiospores** (non-motile endospores *e.g., Mucor*).

REGENERATION

Regeneration is the regrowth in the injured region. It is of two types: (i) **Morphallaxis** : The whole body is formed from a small fragment, *e.g., Hydra*. (ii) **Epimorphosis** : It is the replacement of lost body part. It can be **reparative** (only certain damaged tissues regenerate) or **restorative** (several body parts can redevelop, *e.g.,* broken tail of wall lizard).

Fig.: Regeneration in *Hydra*

VEGETATIVE PROPAGATION

The formation of new plants from vegetative units or propagules such as buds, tubers, rhizomes etc. is known as vegetative propagation. It is of two types- natural and artificial (horticultural).

Natural methods

Vegetative propagules of the plant detach naturally from it and develop into new plants under suitable conditions. It takes place by roots, stems, leaves, bulbils and turions.

Artificial methods

Vegetative propagules are developed by horticulturists to quickly multiply desired varieties of plants from parts of their somatic body. It can be done by cutting, layering, grafting, bud grafting and micropropagation.

Roots

Tap roots of some plants develop adventitious buds to form new plants, *e.g., Dalbergia*. In some plants like sweet potato and *Dahlia* root tubers develop adventitious buds which develop into a new plants.

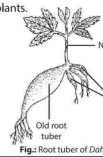


Fig.: Root tuber of *Dahlia*

Leaves

Leaves of many plants have adventitious buds. Such leaves when fall on the ground, their buds develop root, and mature into individual plants, *e.g., Bryophyllum, Begonia* etc.

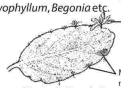


Fig.: Leaf of *Bryophyllum*

Turions

A turion is a swollen bud which contains stored food. It detaches from the parent plant and germinates under favourable conditions *e.g., Utricularia*.

Bulbils

These are multicellular fleshy buds that take part in vegetative propagation, *e.g., Oxalis, Agave* etc.

Fig.: Bulbil of *Agave*

Stems

Certain stem modifications take part in vegetative propagation such as **tubers** (have buds over their nodes or eyes which produce new plantlets when placed in the soil; *e.g.,* potato), **bulbs** (underground condensed shoots with buds which form new plants, *e.g.,* onion), **corms** (unbranched swollen underground stems with circular nodes having buds which germinate into new plants, *e.g., Colocasia*), **rhizomes** (main underground stems with buds which give rise to new aerial shoots during favourable conditions, *e.g.,* ginger), **suckers** (slender underground branches which develop from base of aerial shoot, breaking forms new plants *e.g.,* mint), **runners** (narrow horizontal branches which develop at the base of crown and root at intervals, breaking helps in vegetative propagation, *e.g., Cynodon,*) **stolons** (arched horizontal branches which develop at the base of crown, breaking results in formation of new plant *e.g.,* strawberry), **offsets** (one internode long runners breaking helps in propagation, *e.g., Eichhornia*) and **phylloclades** (each segment of stem can form a new plant, *e.g.,* sugarcane).

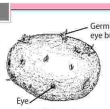


Fig.: Tuber of potato

Cuttings

These are cut pieces of plant parts which are planted in the nurseries. These can be:

(i) **Root cuttings** – The pieces of roots are used to artificially propagate new plants *e.g.,* lemon, orange etc.

(ii) **Stem cuttings** – 20-30 cm long pieces of one year old stems are cut and planted. Before planting they are treated with root promoting chemicals like IBA, *e.g.,* rose, sugarcane etc.

(iii) **Leaf cuttings** – Leaves are cut transversely into 2-3 parts and planted in vertical position in the soil, *e.g., Sansevieria* and *Saintpaulia*.

Bud grafting

Scion is a bud with small piece of bark and cambium. Stock is given a T-shaped cut and bud is inserted in it. The joint is treated with grafting wax and bandaged, *e.g.,* apple, peach etc.

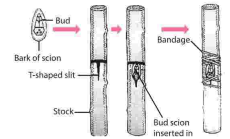


Fig.: Bud grafting

Grafting

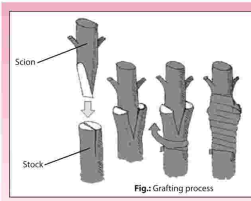


Fig.: Grafting process

Grafting is a technique of connecting two parts, usually a root system and a shoot system of two different plants in such a way that they unite and later develop as a composite plant. A small shoot of plant with superior characters is employed as graft or scion. The root system of the other plant which is disease resistant and has good root system is used as stock (not successful in monocots). It is done in mango, apple etc. The various techniques of grafting are **tongue** grafting, **crown** grafting, **wedge** grafting, **side** grafting and **approach** grafting.

Layering

In this method, adventitious roots are induced to develop on a soft stem by defoliating the soft basal branch and a small injury or cut is given. The injured defoliated part is pegged in the soil to develop adventitious roots. The pegged down branch of the plant is called layer. Once the roots develop, the layer is separated and planted. It can be of following types : **Mound** layering, **Gootee or air** layering, **Simple** layering, **Serpentine** layering and **Trench** layering.

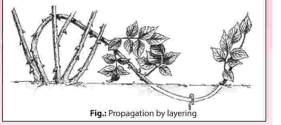


Fig.: Propagation by layering

Micropropagation

This method includes propagation of plants by culturing the cells, tissues and organs. This is known as tissue culture. The culturing results in formation of callus, an undifferentiated mass of cells which later differentiates to form a large number of plantlets. It is useful in obtaining virus free plants, disease free plants, homozygous diploids and quick commercial production of orchids, *Carnation, Gladiolus* etc.

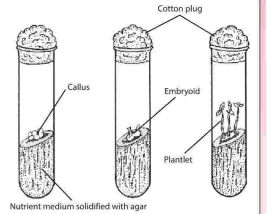


Fig.: Micropropagation

CONCEPT MAP

SEXUAL REPRODUCTION

The process of development of new individuals through the formation and fusion of male and female gametes is known as sexual reproduction or amphimixis or syngenesis.

TYPES

Syngamy

It is the complete and permanent fusion of male and female gametes to form the zygote .

On the basis of source of fusing gametes

Endogamy
It is the fusion of male and female gametes of the same parent, hence, uniparental *e.g., Taenia.*

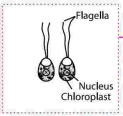
Exogamy
It is the fusion of two gametes produced by different parents, hence, biparental *e.g.,* Rabbit.

Conjugation

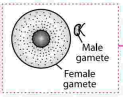
A process of sexual reproduction in which organisms of the same species temporarily couple and exchange or in some cases transfer their genetic material. It takes place in *Paramoecium, Spirogyra,* bacteria etc.

On the basis of structure of fusing gametes

Isogamy
It involves the fusion of gametes which do not differ morphologically but may be different physiologically. It takes place in *Chlamydomonas.*



Anisogamy
It involves the fusion of gametes which differ in size or form. It takes place in *Chlamydomonas,* red algae etc.



Oogamy
It involves the fusion of large non-motile female gamete and a small motile male gamete. It takes place in some algae, vertebrates including human beings and higher invertebrates.

Hologamy
It involves the fusion of two organisms. It occurs in yeasts.

PHASES OF LIFE

Juvenile/Vegetative phase

It is pre-reproductive phase. The period of growth between the birth upto the reproductive maturity of an organism is called the juvenile phase. In plants, it is known as vegetative phase.

Reproductive phase

The period when organisms start producing offspring is called reproductive phase. On the basis of it, plant can be **monocarpic** (flower only once in their life cycle, *e.g.,* bamboo) or **polycarpic** (flower every year in a particular season, *e.g.,* apple).
On the basis of time of breeding, animals are of two types:
(i) **Seasonal breeders:** These animals reproduce at a particular period of the year such as frog, lizard etc.
(ii) **Continuous breeders:** These animals continue to breed throughout their sexual maturity *e.g.,* mice, cattle, etc.

Senescent phase

It is the post-reproductive phase that begins from the end of the reproductive phase. The terminal irreversible stage of ageing is called senescence. It is the last phase of life span and ultimately leads to death.

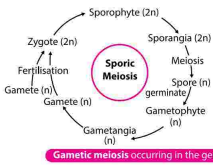
EVENTS IN SEXUAL REPRODUCTION

Pre-fertilisation events

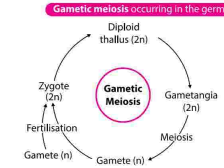
These events of sexual reproduction take place before the fusion of gametes. These include :

Gametogenesis
It is the formation of gametes. Gametes can be **isogametes** (morphologically similar) or **heterogametes** (morphologically dissimilar). Gametes are formed as a result of meiosis which can be of three types:

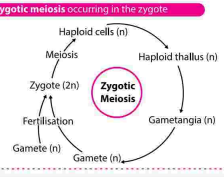
Sporic meiosis occurring inside the sporangia



Gametic meiosis occurring in the germinal cell



Zygotic meiosis occurring in the zygote



Gamete transfer
It is the transfer of gametes to bring them together for fertilisation. In algae, bryophytes and pteridophytes water serves as the medium. In flowering plants it is done by pollination. Animals have copulatory organs to transfer male gametes.

Fertilisation

It is the complete and permanent fusion of two gametes from different or same parent to form a diploid zygote (syngamy). It can be of two types.

External fertilisation
When fertilisation occurs outside the body of the organism, it is called external fertilisation or external syngamy. It requires an external medium such as water, *e.g.,* bony fish and amphibians.

Internal fertilisation
When egg is retained inside female body where it fuses with the male gamete, the process is called internal fertilisation or internal syngamy, *e.g.,* reptiles, birds, mammals etc.

Parthenogenesis

Development of egg (ovum) into a complete individual without fertilisation is known as parthenogenesis. It occurs in rotifers, arthropods, insects etc. It is of two types:

Natural
It occurs regularly in the life cycle of certain animals. It can be complete (occurs in animals which breed exclusively by parthenogenesis), incomplete (occurs in animals in which both sexual reproduction and parthenogenesis occur) and paedogenetic (occurs in larva).

Artificial
In this type, the ovum is induced to develop into a complete individual by artificial stimuli. The stimuli can be physical or chemical.

Neoteny

When the larva retains adult characters such as gonads and starts producing young ones by sexual reproduction, it is called neoteny. It occurs in axolotl larva.

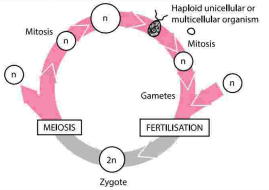
Embryogenesis
During embryogenesis zygote undergoes mitotic cell division and cell differentiation. On the basis of development of zygote, animals can be **oviparous** (egg- laying; zygote develops outside the female body) *e.g.,* all birds, most reptiles etc., **viviparous** (zygote develops inside the female body) *e.g.,* mammals (except egg laying mammals) or **ovoviviparous** (retains egg inside; zygote development is internal) *e.g.,* sharks.
In flowering plants, zygote is formed inside the ovule. After fertilisation the ripened ovary forms the fruit. The ovules mature and get converted into seeds. The ovary wall produces pericarp which protects the seeds.

Post-fertilisation events

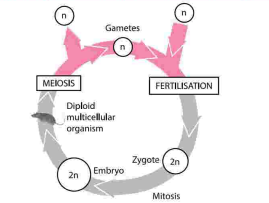
It includes development of zygote and embryogenesis.

Development of zygote
The zygote formed by fusion of two gametes is always diploid. It is a link between one generation and next generation. The development of zygote depends upon the type of life cycle of the organisms and environmental conditions. There are three types of life cycles:

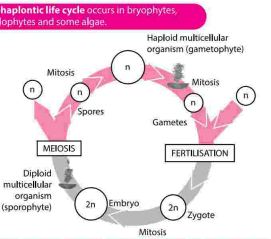
Haplontic life cycle occurs in many algae and fungi



Diplontic life cycle occurs in higher animals and seed bearing plants



Diplohaplontic life cycle occurs in bryophytes, pteridophytes and some algae.



SPECIAL MODES OF REPRODUCTION

HUMAN MALE REPRODUCTIVE SYSTEM

The male reproductive system is located in the pelvis region. It is a system of sex organs and accessory glands. It main functions are:

- Production of sperms by spermatogenesis.
- Secretion of male sex hormone testosterone.
- Ensures internal fertilisation.

CONCEPT MAP

Primary sex organs

- Produce male gametes or **sperms**.
- Secrete male sex hormone or **testosterone**.

Testes in scrotum

- Abdominal in early foetal life; extra-abdominal later.
- Descend into pouch like scrotum in 7th month of embryonic development through inguinal canal.
- A pair of testes is suspended in scrotum by **spermatic cords.**
- Temperature is **2-2.5°C** lower than internal body temperature.
- Under hormonal control of **FSH** and **LH** from anterior lobe of pituitary.

Seminal vesicles

- A pair of sac like structures near the base of bladder.
- Produce an alkaline secretion, **seminal fluid** (pH 7.4), which forms 60% of volume of semen.
- Seminal fluid is rich in **fructose** for nourishing sperms; **prostaglandins**, which stimulate uterine contractions for upward movement of sperms and **clotting proteins** for coagulation of semen after ejaculation.

Prostate gland

- Single gland, produces a milky secretion (pH 6.5), which forms 25% of volume of semen.
- Prostate secretion contains citric acid, enzymes (acid phosphatase, amylase, pepsinogen), and prostaglandins.
- Secretions nourish and activate the spermatozoa to swim.

Cowper's/bulbourethral glands

- A pair of glands present on either side of membranous urethra.
- Secrete alkaline fluid and mucus that lubricates the end of penis and lining of urethra.

Protective coverings

- 3 Protective covering or tunicae surround each testis.

Tunica vaginalis

- Flat sac, having a narrow coelomic cavity.
- Helps the testis in frictionless sliding.

Testicular lobules

- 250 compartments called testicular lobules are present in each testis, with 1-3 **seminiferous tubules** in each lobule, alongwith connective tissue.
- Connective tissue contains endocrine cells called **Leydig's cells**.

Tunica albuginea

- Fibrous covering of each testis, lying below tunica vaginalis.
- Divides each testis into about 250 testicular lobules by forming vertical partition (**mediastinum**) and transverse septa.

Seminiferous tubules

- Wall of each seminiferous tubule is formed of single layered **primordial germinal epithelium**, PGC, of cuboidal cells, and tall **sertoli** or **sustentacular** cells.

Leydig's or Interstitial cells

- Endocrine part of testis.
- Secrete androgens, *e.g.*, **testosterone**, which maintain male sexual characteristics and also stimulate spermatogenesis in germinal epithelium.

Tunica vasculosa

- Consists of rich network of capillaries, supported by delicate loose connective tissue which lines tunica albuginea.

Germinal epithelium

- PGC undergo spermatogenesis to form spermatozoa.

Sertoli / Sustentacular cells

- Large, pyramidal cells, projecting into lumen of seminiferous tubules, provide attaching sites to spermatocytes and spermatids.
- Secrete **androgen binding protein** (ABP) that concentrates testosterone in the seminiferous tubules.
- Function in response to FSH, secrete **inhibin** which suppresses FSH synthesis by negative feedback.

Secondary sex organs

Accessory glands

- Secrete seminal plasma or semen rich in fructose, calcium, prostaglandins clotting proteins and certain enzymes.

Accessory ducts

- Store and transport sperms from the testes to the outside through urethra.
- Include intratesticular genital duct system and vasa deferentia.

Intratesticular genital duct system

Rete testis

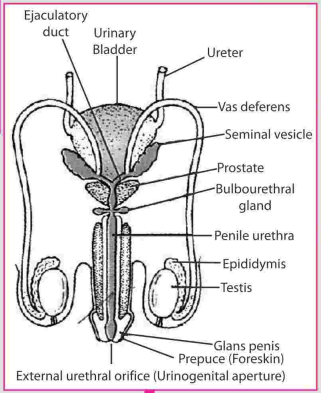
- Network of 20-30 fine channels into which seminiferous tubules open.

Vasa efferentia

- 10-20 fine tubules connecting rete testis with epididymis, lined by many **ciliated cells**, which help in conducting sperms, and **endocytic cells** that remove debris accompanying sperms.

Epididymis

- Differentiated into anterior **caput epididymis**, middle **corpus epididymis** and posterior **cauda epididymis**.
- Store sperms and also secrete nutrients required for maturation of spermatozoa.



Vasa deferentia

- Conduct sperms.
- Leave the scrotal sac and enter abdominal cavity through inguinal canal.
- Joined by duct from seminal vesicle to form ejaculatory duct.

Ejaculatory ducts

- 2 short tubes each formed by union of duct from a seminal vesicle and a vas deferens.
- They pass through prostate gland and join prostatic urethra to produce single **urinogenital duct**.
- Muscular walls of ejaculatory ducts quickly conduct ejaculate through urinogenital duct.

Urethra

- Much longer, as compared to females, about **20 cm**, common pathway for urine and semen; functioning regulated by internal and external sphincters.
- Differentiated into anterior **prostatic urethra**, surrounded by prostate gland carrying urine only; middle **membranous urethra,** which receives ducts from cowper's gland; and distal **penile urethra**, which opens to the outside through penile meatus.

Penis

- Erectile male copulatory organ.
- Conducts both urine and semen, opens to the outside by urinogenital aperture on glans penis, covered by prepuce.
- Contains three cylindrical masses of erectile tissue - two dorsal **corpora cavernosa** and one ventral **corpus spongiosum**, which help in stiffening during copulation.
- Helps to transfer semen to female reproductive tract resulting in internal fertilisation.

Disorders of the male reproductive system

BPH or Benign prostatic hypertrophy

- Enlargement of prostate gland, common in old age.
- Nocturia, dysuria and may lead to kidney damage.

Impotence

- Inability of adult male to achieve or hold penile erection.
- Occurs due to psychological, physiological or neuromuscular defects.

Prostate cancer

- Common malignancy, accounting for 2-3% of male deaths.
- Dysuria, difficulty in voiding, increased frequency of urination.
- Treatment involves surgical removal of testes.

Sterility

- Inability of sperms to fertilise the ovum, due to low sperm count or low sperm motility.

HUMAN FEMALE REPRODUCTIVE SYSTEM

CONCEPT MAP

The human female reproductive system is located in the pelvic region and consists of a pair of ovaries, alongwith a pair of oviducts, uterus, cervix, vagina, external genitalia and glands. Breasts or mammary glands are considered part of the female reproductive system, because of their role in nourishing the offspring. Main functions of female reproductive system are:

- Production of ova by oogenesis.
- Secretion of female sex hormones *e.g.*, estrogen, progesterone, etc.
- Fertilization, pregnancy, giving birth and child care.

Primary sex organs

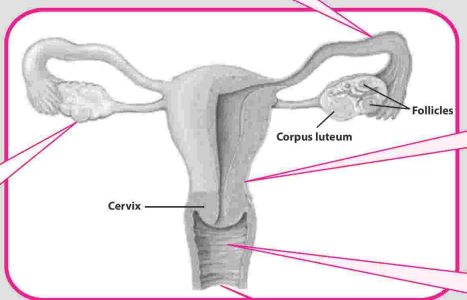
Secondary sex organs

Ovary

- Paired structures located in upper pelvic cavity.
- 2 to 4 cm in length, shaped like an unshelled almond.
- Ovarian ligament attaches the ovary to uterus.
- Covered by a layer of cubical epithelium called the germinal epithelium and further by visceral peritoneum. Beneath the epithelium is **tunica albuginea**- a layer of connective tissue.
- Underlying tunica albuginea is the ovarian **stroma,** differentiated into dense outer layer called **cortex,** and a less dense inner portion called **medulla.**
- Interspersed throughout the cortex are many ovarian follicles in different stages of development and are called primary, secondary, tertiary and Graffian (mature) follicles.
- A mature Graffian follicle consists of an oocyte surrounded by a homogenous membrane **zona pellucida** and radially elongated follicle cells called **corona radiata,** further surrounded by follicular cells forming **membrana granulosa.**
- Granulosa cells are differentiated into outer fibrous **theca externa** and inner cellular **theca interna** which secrete a fluid called **liquor folliculi** creating a large cavity called **antrum** or follicular cavity.
- Oocyte adheres to the granulosa layer by a stalk called **cumulus ovaricus** or **cumulus oophorus.**
- Total number of follicles in two ovaries of a normal young adult woman is about four lakhs, but only 450 mature during the entire reproductive span. Many ovarian follicles undergo degeneration, called **follicular atresia.**
- Graafian follicle releases an oocyte during ovulation and converts into a yellow body called **corpus luteum,** which secretes mainly progesterone and some relaxin hormone.
- In absence of fertilization, corpus luteum degenerates about 12 days after ovulation becoming the corpus albicans which is replaced by connective tissue and over months is absorbed.
- Ovaries perform two functions: production of ova and secretion of female sex hormones.

Fallopian tube/oviduct

- There are two Fallopian tubes and each is about 10-12 cm long consisting of infundibulum, ampulla and isthmus.
- The **infundibulum** is a dilated trumpet- like portion of the Fallopian tube, with fingerlike projections called **fimbriae,** and an **ostium** which helps in collection of the ovum after ovulation.
- **Ampulla** is the widest and longest part of the Fallopian tube. **Isthmus** is the short, narrow thick-walled portion that follows the ampulla. Fertilization of ovum occurs at the **ampullary-isthmic junction.**
- **Uterine part** passes through the uterine wall and communicates with the uterine cavity.
- Function of the Fallopian tube is to convey the ovum from ovary to the uterus by peristalsis.



Uterus

- Also known as metra/hystera/womb.
- It is a hollow muscular, inverted pear shaped structure lying in the pelvic cavity between the urinary bladder and the rectum.
- It is differentiated into the following parts:

(i) Fundus is the upper dome-shaped part of the uterus, above the openings of the uterine parts of the Fallopian tubes.

(ii) Cornua (*sing.* cornu) are upper corners where the oviducts enter the uterus.

(iii) Body is the main part, which is narrowest inferiorly, where it continues with the cervix.

(iv) Cervix joins the anterior wall of vagina and opens into it. The cervix communicates above with the body of uterus by an aperture called **internal os,** and with the vagina by an opening, **external os.**

- Walls of the uterus are composed of three layers of tissues, (i) **perimetrium-** outer thin covering of peritoneum, (ii) **myometrium-** middle thick layer of smooth muscle fibres that shows strong contraction during delivery of the baby and (iii) **endometrium-** inner glandular layer that lines the uterine cavity and undergoes cyclical changes during menstrual cycle.
- After puberty, the uterus goes through the menstrual cycle in absence of fertilization.
- After fertilization, embryo gets attached to the uterine wall, where it is nourished and protected and menstruation is temporarily suspended.

Vagina

- A tube that extends from cervix to the outside of the body.
- A passageway for menstrual flow, receptacle for sperms during intercourse, and part of the birth canal, during labour.
- The opening of vagina, called vaginal orifice is partially covered by a membrane called **hymen.**
- Two Fallopian tubes (oviducts), uterus and vagina constitute the female accessory ducts.

External genitalia

- Collectively called vulva or pudendum. It is differentiated into the following parts:

(i) Mons pubis : Anterior most portion of the external genitalia, consists of fatty tissue covered by skin and pubic hair.

(ii) Clitoris : Posterior to mons pubis; homologous to glans penis of male.

(iii) Labia majora : Two large fleshy folds of skin, which form the boundary of vulva; partly covered by pubic hair and contain large number of sebaceous (oil) glands; homologous to scrotum of the male.

(iv) Labia minora : Two smaller folds of skin lie under the labia majora; are homologous to penile urethra of male. The area between the labia minora is called **vestibule.** Posteriorly the labia minora are fused to form **fourchette.**

(v) Perineum : The area which extends from the fourchette to anus.

Glands

- **Vestibular glands :** They are of two types-
  - **Lesser vestibular glands/paraurethral glands/ glands of Skene** are numerous minute glands present on either side of urethral orifice; homologous to male prostate and secrete mucus.
  - **Greater vestibular glands/ Bartholin's glands** are paired glands, situated one on each side of vaginal orifice; homologous to bulbo-urethral/ Cowper's glands of male and secrete viscid fluid that supplements lubrication during sexual intercourse.
- **Mammary glands or breasts :** These are modified sweat glands.
  - In females, breasts are undeveloped, until puberty.
  - Externally, each breast has a projection, *i.e.,* **nipple** surrounded by a circular pigmented area of skin called **areola.**
  - Mammary glands consist of glandular, fibroid and adipose tissues.
  - **Glandular tissue** comprises 15-20 lobes in each breast. Each lobe is made up of a number of lobules, which contain grape like clusters of milk secreting glands called **alveoli.**
  - When milk is produced, it passes from alveoli into the **mammary tubules** and then into **mammary ducts.** Near the nipple, mammary ducts expand to form **mammary ampullae,** where some milk may be stored, before going to **lactiferous ducts** from which, it is secreted out.
  - **Fibrous tissue** supports the alveoli and ducts.
  - **Fatty or adipose tissue** is found between the lobes and covers the surface of the gland. The amount of adipose tissue determines the size of the breasts.
  - Main function of mammary glands is secretion and ejection (release) of milk.
  - Milk production is stimulated by hormone prolactin, and ejection of milk by the hormone oxytocin.

Disorders of female reproductive system

Breast cancer
- It is rarely seen before age of thirty; incidence increases after menopause.
- Standard treatment is mastectomy.

Ectopic pregnancy
- It is implantation of embryo at a site other than uterus, generally in the oviduct.

Menstrual disorders
- Amenorrhea - Absence of menstruation.
- Menorrhagia - Excessive menstruation.
- Dysmenorrhea - Painful menstruation.

Infertility
- In women, infertility is inability to become pregnant.
- It may be due to failure to ovulate or any anatomical factor which prevents the union of egg and sperm or subsequent implantation.

CONCEPT MAP

GAMETOGENESIS

Gametogenesis is the process by which male and female sex cells or gametes *i.e.,* sperms and ova are formed respectively in the male and female gonads (testes and ovaries). It is the major reproductive event in sexual reproduction.

Spermatogenesis

- Process of sperm formation in testes after puberty.
- Occurs in seminiferous tubules of testes, which are lined by germinal epithelium, consisting of primordial germ cells (PGCs) and Sertoli (nurse) cells.
- Includes formation of spermatids and formation of spermatozoa.
- PGCs are largely cuboidal in outline, which divide first by **mitosis** and later by **meiosis**.
- Four sperms are produced from one spermatogonial cell.
- Consists of multiplication, growth, maturation and differentiation phases.

Multiplication phase

- At sexual maturity, the PGCs divide several times by mitosis to produce a large number of **spermatogonia (2n)**.
- Spermatogonia are of two types: **Type A spermatogonia**, which serve as stem cells, and **type B spermatogonia,** which are the **precursors of sperms**.

Growth phase

- Each type B spermatogonium actively grows to a larger **primary spermatocyte (2n)** by obtaining nourishment from the Sertoli cells.

Maturation phase

- Each primary spermatocyte undergoes two successive divisions of meiosis.
- As a result of Ist meiotic division, which is reductional division, two haploid **secondary spermatocytes (n)** are produced.
- Secondary spermatocytes undergo the IInd meiotic division, which is an equational or mitotic division, producing four haploid **spermatids (n)**.

Differentiation phase or Spermiogenesis

- It is the transformation of the spermatids into **spermatozoa**, or **sperms** in about 64 days, and involves the following changes:
  - Formation of acrosome by Golgi apparatus; elongation and condensation of nucleus; formation of axial filament from distal centriole; separation of centrioles; development of mitochondrial spiral; formation of flagellum.
- **Sperm/Spermatozoan :** Sperms are microscopic, motile and remain viable for 24 to 48 hrs, after their release in the female genital tract.
- A typical spermatozoan consists of head, neck, middle piece and tail.
- **Head :** Contains anterior acrosome and posterior nucleus; acrosome contains sperm lysins for egg penetration during fertilisation.
- **Neck :** Very short; connects head to middle piece; contains proximal centriole towards the nucleus, which has a role in the first cleavage of the zygote and distal centriole, that gives rise to the axial filament of the sperm.
- **Middle piece :** Bears the mitochondrial spiral, therefore called 'power house of sperm'; ring centriole or annulus, with unknown function at the end of middle piece.
- **Tail :** It is several times longer than the head; the sperm swims about by its tail in a fluid medium.

Spermiation

It is the process of release of sperms from the Sertoli cells. Sperms, after release are stored in epididymis and upper portion of vasa deferentia for upto one month, where they obtain nourishment from epithelium of epididymis and gain motility.

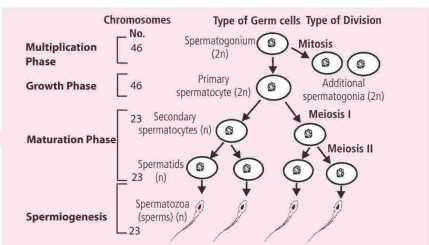
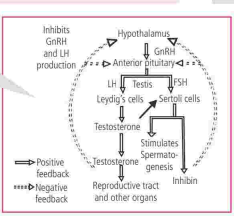
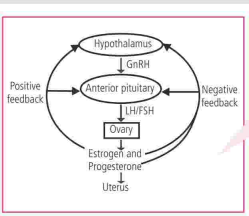


Fig.: Stages in spermatogenesis (diagrammatic)

Hormonal control

- Spermatogenesis is initiated due to increase in GnRH by hypothalamus.
- GnRH acts on anterior lobe of pituitary to secrete LH and FSH.
- LH acts on Leydig's cells to secrete testosterone.
- FSH acts on Sertoli cells to secrete ABP and inhibin.
- FSH also stimulates spermatogenesis, thus promoting sperm production.
- ABP concentrates testosterone in the seminiferous tubules.
- Inhibin suppresses FSH synthesis.





Hormonal control

Oogenesis is initiated due to increase in GnRH by hypothalamus; GnRH acts on anterior lobe of pituitary to secrete FSH and LH; FSH stimulates follicular growth and maturation of oocyte; FSH stimulates the follicular granulosa cells to secrete estrogen; LH stimulates corpus luteum to secrete progesterone.

Oogenesis

- Process of ovum formation, which starts in the foetal ovary (25 weeks old) and is completed after puberty.
- Occurs in the germinal epithelium of the foetal ovary.
- Results in the formation of one ovum and three polar bodies, every month, after puberty.
- Cells of germinal epithelium, larger than the others, function as **germ cells**.
- Germ cells divide first by **mitosis** and then by **meiosis**.
- Consists of multiplication, growth and maturation phases.

Multiplication phase

- Germ cells in the foetal ovary divide by mitosis to form millions of egg mother cells or **oogonia**.
- Oogonia form **egg tubes** into the stroma of ovary, which form a multicellular mass called **egg nest**.
- All the oogonia are formed in the foetal ovary, and no more are formed after birth.

Growth phase

- One oogonium of the egg nest grows in size forming **primary oocyte**, surrounded by layer of granulosa cells, forming primary follicle.
- Total number of **primary follicles** in foetal ovary is about 60 lakhs.
- Large number of primary follicles undergo **follicular atresia**, so that a young adult woman has only about 4 lakhs primary follicles in both ovaries.

Maturation phase

- Primary oocyte begins meiosis I, but division is arrested at diakinesis of prophase I.
- Ovarian follicle containing primary oocyte occurs in the foetal ovary and remains so, till puberty.
- At puberty, primary oocyte grows and completes meiosis I, producing large **secondary oocyte (n)** and small **polar body** or **polocyte (n)**.
- Secondary oocyte proceeds with meiosis II, but the division gets arrested in metaphase II, followed by ovulation.
- Meiosis II is completed only after entry of sperm, resulting in the formation of ovum and another polar body.

Ovulation

- It is the release of secondary oocyte, after puberty, once every month from Graafian follicle, by any one ovary. Only 450 secondary oocytes are produced during the entire reproductive span. Ruptured Graafian follicle forms corpus luteum.
- **Ovum :** Spherical, alecithal, with cytoplasm containing germinal vesicle or nucleus, nucleolus and cortical granules; cytoplasm protected by plasma membrane; shows polarity, differentiated into an animal pole and a vegetal pole; centrioles absent, protected by two coverings.
- **Corona radiata :** Outer, multicellular covering of radially elongated follicular cells, held together by hyaluronic acid.
- **Zona pellucida :** Inner, noncellular, glycoprotein rich covering with receptor proteins; bears ingrowth of follicular cells for transfer of nutrients to the egg.
- **Perivitelline space :** Narrow space present between plasma membrane and zona pellucida.

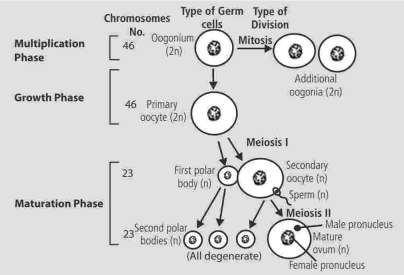


Fig.: Stages in oogenesis (diagrammatic)

CONCEPT MAP

DNA REPLICATION

Replication is the process of formation of carbon copies of DNA. The primary function of DNA replication is to provide same genetic material as possessed by the parent to the progeny. Thus, the replication of DNA must be complete and carried out in such a way as to maintain genetic stability within the organism and the species. For replication, DNA itself functions as template, therefore, DNA replication is an autocatalytic function of DNA. It occurs during S-phase of the cell cycle and is a multistep complex process which requires over a dozen of enzymes and protein factors.

Semi-conservative Replication

DNA replication is **semi-conservative** *i.e.*, a type of replication in which one strand of the daughter duplex is derived from the parent while the other strand is formed anew. The parent strands are separated and act as template for synthesis of new daughter strand. The new strand has complementary base pairs to template strand. (A opposite T and G opposite C).

DNA Polymerase

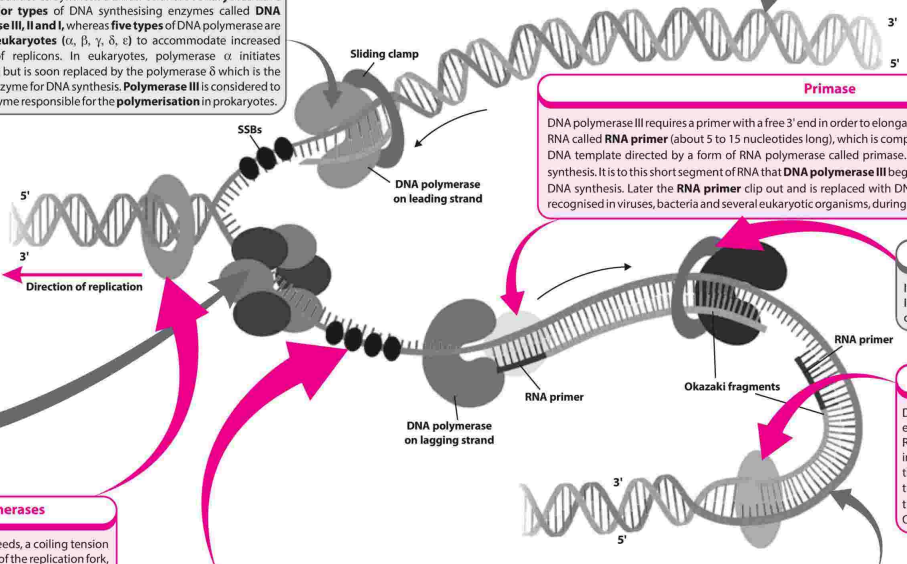
The main enzyme of replication is **DNA dependent DNA polymerase** that catalyses the polymerisation of deoxynucleotides to synthesise a new strand. **Prokaryotes** have **three major types** of DNA synthesising enzymes called **DNA polymerase III, II and I,** whereas **five types** of DNA polymerase are found in **eukaryotes** (α, β, γ, δ, ε) to accommodate increased number of replicons. In eukaryotes, polymerase α initiates replication but is soon replaced by the polymerase δ which is the primary enzyme for DNA synthesis. **Polymerase III** is considered to be the enzyme responsible for the **polymerisation** in prokaryotes.

DNA Polymerase in Prokaryotes and Eukaryotes

DNA polymerase I demonstrates 5′→3′ exonuclease activity apart from 3′→5′ exonuclease activity. Polymerase I is believed to be responsible for removing the primer, as well as for filling the gaps which naturally occur as primers are removed. Its exonuclease activity also allows for proofreading during this process, a form of DNA repair. **Polymerase II** is also involved in DNA repair. The **3′→5′ exonuclease** activity of polymerase III provides its **proofreading function**. **Polymerase** ε in eukaryotes may help in synthesis of lagging strand along with other roles and **polymerase** β helps in DNA repair.

Leading Strand

DNA polymerase can polymerise nucleotides only in **5′→3′ direction** because it adds them at the 3′ end. Since the two strands of DNA run in **antiparallel direction,** the two templates provide different ends for replication. Replication over the two templates thus, proceeds in **opposite direction.** The strand with polarity 3′→5′ forms its **complementary** strand continuously because 3′ is always open for elongation. It is called **leading strand** with polarity 5′→3′.



Primase

DNA polymerase III requires a primer with a free 3′ end in order to elongate a polynucleotide chain. A short segment of RNA called **RNA primer** (about 5 to 15 nucleotides long), which is complementary to DNA, is first synthesised on the DNA template directed by a form of RNA polymerase called primase. It does not require a **free 3′ end** to initiate synthesis. It is to this short segment of RNA that **DNA polymerase III** begins to add 5′-deoxyribonucleotides, initiating DNA synthesis. Later the **RNA primer** clip out and is replaced with DNA. RNA priming is a universal phenomenon recognised in viruses, bacteria and several eukaryotic organisms, during the initiation of DNA synthesis.

Sliding clamp or DNA clamp

It is an important protein of DNA polymerase III holoenzyme that prevents the dissociation of polymerase from template strand of DNA.

Origin of Replication

Replication begins at a particular region called **origin of replication** or *Ori* on the chromosome. Most of the bacterial DNA has single *Ori* hence functions as a **replicon** while eukaryotes have multiple *Ori* (multirepliconic). The interaction of specific proteins with *Ori* defines the start site of replication and provides a short region of ssDNA to initiate synthesis of the nascent DNA at each point along the chromosome where replication is occurring.

DNA Ligase

Discontinuous synthesis of DNA requires enzyme DNA ligase that both removes the RNA primer and unites the Okazaki fragments into the lagging strand. DNA ligase, catalyses the formation of the **phosphodiester bond** that seals the nick between the 3′-hydroxyl of the growing strand and 5′-phosphate of an Okazaki fragment.

Helicases

These are the proteins/enzymes which act over the *Ori* site in order to unwind the two strands of DNA by breaking hydrogen bonds. One particular protein **DnaA** initiates first step in unwinding of DNA helix**.** This facilitates the subsequent binding of **DnaB** and **DnaC** proteins that further open and destabilise the helix. The energy required by the proteins to break hydrogen bonds or denaturing the double helix is supplied by the hydrolysis of ATP. The separation of strands create a **replication fork**. Such a fork will initially appear at the point of origin of synthesis and then move along the DNA duplex as replication proceeds. Replication is **bidirectional** and **two forks**, migrate in opposite directions away from the origin.

Topoisomerases

As unwinding proceeds, a coiling tension is generated ahead of the replication fork, often producing supercoiling. Such supercoiling can be relaxed by **DNA gyrase**, a member of a larger group of enzymes referred to as DNA topoisomerases. The gyrase makes either single or double stranded "cuts" and catalyses localised movements that have the effect of "undoing" the twists and knots created during supercoiling. The strands are then resealed. These various reactions are driven by the energy released during ATP hydrolysis.

Single Strand Binding Proteins

The separated strands are stabilised and maintained by **single strand binding proteins (SSBs)** which prevent premature reannealing of ssDNA to dsDNA. This allows enzymes including helicase, primase and DNA polymerase, to bind and initiate DNA synthesis.

Proofreading and Error Correction

Although the action of DNA polymerase is very accurate, synthesis is not perfect and a noncomplementary nucleotide is occasionally inserted erroneously. To compensate for such inaccuracies, all DNA polymerases possess **3′→5′ exonuclease activity.** This property enables them to detect and excise a mismatched nucleotide (in the 3′→5′ direction). Once the mismatched nucleotide is removed, 5′→3′synthesis can again proceed. This process **increases the fidelity** of synthesis.

Lagging Strand

Lagging strand is the strand synthesised In direction opposite to the growing replication fork, *i.e.*, (3′ → 5′). Here, the DNA is synthesised discontinuously in short (1-5 kb) fragments, known as **Okazaki fragments**. Several Okazaki fragments (upto a thousand) must be sequentially synthesised for each replication fork. To ensure that this happens, the helicase associates with the primase. This allows the RNA primer to be made and, in turn, the polymerase begin replication of DNA. An RNA primer is required every time to form a new Okazaki fragment.

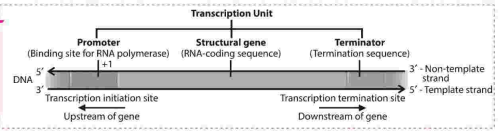
CONCEPT MAP

TRANSCRIPTION

Transcription is the process of copying of genetic information from template strand of DNA to an RNA molecule. Template strand refers to DNA strand that directs synthesis of RNA and have 3' → 5' polarity. The other strand having 5'–3' polarity is called antisense strand. RNA synthesis occurs in 5' → 3' direction and requires an enzyme complex called RNA polymerase and other initiation and termination proteins.

TRANSCRIPTION UNIT

Refers to the sequence of nucleotides in DNA that codes for an RNA molecule along with other sequences necessary for transcription.

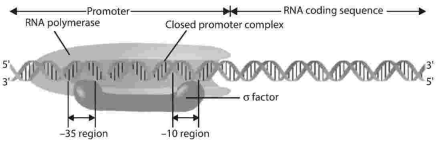


- Transcription takes place in cytoplasm.
- **Structural genes** are polycistronic *i.e.*, encodes for more than one polypeptide.
- **Promoters include** (i) "– 10 sequence" is TATAAT; called "Pribnow box". (ii) "–35 sequence" is TTGACA, called "recognition sequence".
- Only one type of RNA polymerase is involved, represented by $(2\alpha\beta\beta'\omega)\sigma$.

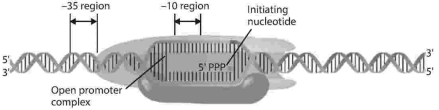
IN PROKARYOTES

The sigma (σ) factor binds to promoter site of DNA and initiates transcription.

1. In initiation, the RNA polymerase holoenzyme first recognises the promoter at the -35 region and binds to the full promoter.



2. As initiation continues, RNA polymerase binds more tightly to the promoter at the -10 region, accompanied by a local untwisting of the DNA in that region. At this point, the RNA polymerase is correctly oriented to begin transcription.



MECHANISM OF TRANSCRIPTION

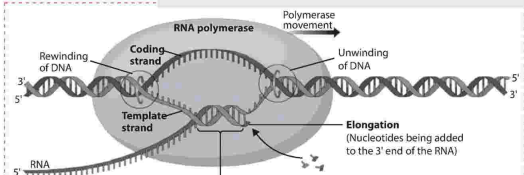
Involves three steps:

Initiation

Just before initiation, RNA polymerase and accessory proteins bind to a DNA molecule upstream of the initiation point. The DNA is unwound to separate and expose the strand to be transcribed. Then, the RNA polymerase complex binds to promoter sequence, which initiates transcription. Polymerase begins to synthesise a strand of RNA complementary to one side of the DNA strand, moving into the coding sequence portion of the gene being transcribed. The enzyme and the factors involved are different in both eukaryotes and prokaryotes.

Elongation

During elongation, a lengthening RNA molecule is synthesised by DNA polymerase as it reads the DNA triplet code on the template strand. The DNA polymerase will continue reading the template until it reaches a sequence that provides a signal indicating that transcribed region is at an end. Another RNA polymerase can attach to the promoter to begin synthesising another RNA before the first one is finished.

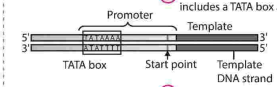


Termination

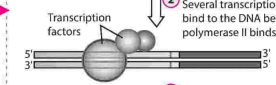
Termination of transcription is triggered when the RNA polymerase encounters a particular DNA sequence, causing the polymerase to lose affinity for the DNA template. At this point, RNA polymerase disengages from the DNA and the RNA molecule is released for translation or post-transcriptional processing.

IN EUKARYOTES

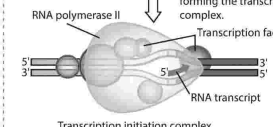
1. An eukaryotic promoter includes a TATA box and CAAT box



2. Several transcription factors must bind to the DNA before RNA polymerase II binds to it



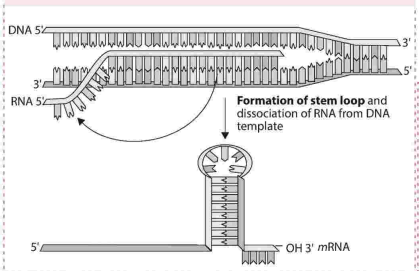
3. Additional transcription factors bind to the DNA along with RNA polymerase II, forming the transcription initiation complex.



Sigma factor is absent and primer is not required.

- Transcription takes place in nucleus.
- **Structural genes** are monocistronic *i.e.*, encodes for single polypeptide.
- **Promoters include**- (i) "–25 sequence" is TATAAAA, called "Hogness box" or "TATA box" (ii) "–75 sequence" is GGCCAATCT, called "CAAT box".
- Besides promoters, eukaryotes also require enhancers.
- Three types of RNA polymerases are involved: RNA Pol I (transcribes *r*RNAs), RNA Pol II (transcribes *m*RNA, hnRNA), RNA Pol III (transcribes tRNA, 5SrRNA, etc.)

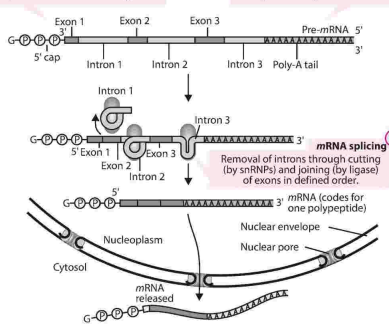
- **Termination** may or may not require rho (σ) factor.
- *m*RNA do not undergo any processing and may undergo translation before the completion of transcription *i.e.*, coupled as both the processes takes place in cytosol and in 5' → 3' direction.
- Most prokaryotic *m*RNAs terminate with the sequence 5'-UUUUUUA-3', which allows nascent transcript to form **hairpin loop** that disrupts the RNA-DNA hybrid as well as the interaction between DNA and polymerase resulting in dissociation and termination of transcription of RNA molecule.



Post Transcriptional Modifications of hnRNA

1. **Capping**
Addition of methyl guanosine triphosphate (mGPPP) that protects *m*RNA from nucleases and provides ribosome binding site.

2. **Tailing**
Addition of 200-300 polyadenylate residues with the help of poly A polymerase. It protects 3' end from degradation by exonucleases.



- **Termination** - Coupled transcription - translation is not possible in eukaryotes, as transcription products *i.e.*, RNA pass from nucleus to cytoplasm for translation. The nascent RNA *i.e.*, hnRNA or primary transcript undergoes modifications to form functional *m*RNA.

CONCEPT MAP

TRANSLATION

Translation is the process by which a protein or polypeptide is synthesised inside the living cell using *m*RNA as a template. This biochemical process is called translation because the information present in the form of four letter alphabet of nucleic acid is translated into twenty letter alphabets of proteins.

Translational Machinery

- Basic translational machinery is same in eukaryotes and prokaryotes, however few differences occur. It is composed of five components, *i.e.*, *m*RNA, *t*RNA, amino acid, enzymes (aminoacyl *t*RNA synthetase, peptidyl transferase) and ribosome.
- In eukaryotes, each *m*RNA is **monocistronic** (encodes for only one polypeptide) whereas in prokaryotes, many *m*RNAs are **polycistronic** (encodes for two or more different polypeptides).
- **Ribosome** is the **site of protein synthesis**. **70S** (30S + 50S) ribosomes are involved in prokaryotic translation while **80S** (40S + 60S) ribosomes are involved in eukaryotic translation. The two subunits of ribosomes associate at the time of protein synthesis and then separate after the completion of process. Ribosomes have three sites; **the peptidyl (P) site**, **aminoacyl (A) site** and **exit (E) site**. Eukaryotic ribosomes do not have E-site.
- *t*RNAs pick up particular amino acids (at CCA or 3′ end) and take the same to *m*RNA over particular codons corresponding to their anticodons. Each *t*RNA contact with ribosome at T ψ C loop and the enzyme aminoacyl *t*RNA synthetase at DHU loop. Eukaryotic *m*RNAs have 5′- cap and poly A tail at 3′end.

MECHANISM OF TRANSLATION

- The steps of translation are common in both prokaryotes and eukaryotes. Three main steps involved in translation are initiation, elongation and termination. Before initiation amino acids are activated and attached to *t*RNAs in two steps called activation of amino acids and charging or aminoacylation of *t*RNA respectively.
- In eukaryotes, the initiating amino acid is methionine, not N-formylmethionine (*f*Met) as in prokaryotes.
- The main difference between initiation of translation in prokaryotes and eukaryotes is that in bacteria, a Shine-Dalgarno sequence (4 to 9 purine residues, 8 to 13 base pairs to the 5′ side of initiation codon) guides correct initiation codon (5′AUG) and is the binding site for the 30S ribosomal subunit.
- In contrast, most eukaryotic *m*RNAs do not contain Shine-Dalgarno sequences. Instead, a 40S ribosomal subunit attaches at the 5′ end of the *m*RNA and moves downstream (*i.e.*, in a 5′ to 3′ direction) until it finds the AUG initiation codon. This process is called **scanning**.

1 Activation of amino acid and Charging of *t*RNA

- Amino acids are activated by activating enzymes, aminoacyl *t*RNA synthetases in presence of ATP to produce aminoacyl-adenylate-enzyme complex.

$$\underset{\text{Amino acid}}{AA} + ATP + \text{Enzyme} \xrightarrow{Mg^{2+}} \underset{\text{Aminoacyl-adenylate enzyme-complex}}{AA \sim AMP - E} + PPi$$

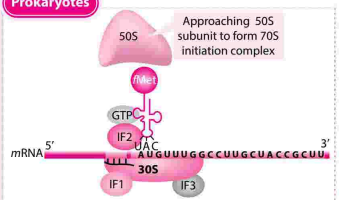
- This complex reacts with *t*RNA specific for the amino acid. Amino acid links to 3′ – OH end of *t*RNA through its – COOH group to form aminoacyl *t*RNA complex.

$$\underset{\text{Aminoacyl adenylate enzyme}}{AA \sim AMP - E} + tRNA \rightarrow \underset{\text{Charged tRNA}}{AA - tRNA} + AMP + E$$

Prokaryotes

2 Initiation

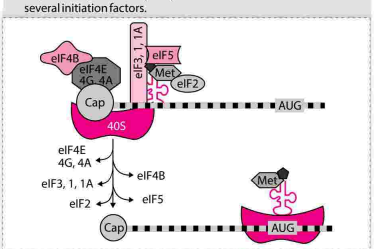
- 3 initiation factors are required *i.e.*, **IF1, IF2** and **IF3**.
- Initiation begins with the binding of **IF1** and **IF3** to the small (30S) ribosomal subunit.
- The small subunit then binds to the *m*RNA *via* complementary pyrimidine rich sequences close to 3′end of 16S *r*RNA guided by Shine-Dalgarno sequence and moves 3′ along the *m*RNA until it locates the AUG initiation codon.
- The initiator *t*RNA charged with N-formylmethionine and a complex of IF2 and GTP (*f*Met-*t*RNA$_f^{Met}$/IF2/GTP) now binds to *m*RNA and 30S subunit.
- The complex of *m*RNA, *f*Met-*t*RNA$_f^{Met}$, IF1, IF2 and the 30S ribosomal subunit is called the **30S initiation complex**.
- Structural changes then lead to the ejection of IF1 and IF3 and IF2 now stimulates the association of 50S subunit of ribosomes. Simultaneously, the GTP bound to IF2 is hydrolysed to GDP and Pi and leading to release of IF2. This forms **70S initiation complex**.
- When this complex is formed, the ribosome is ready for the elongation phase.



Eukaryotes

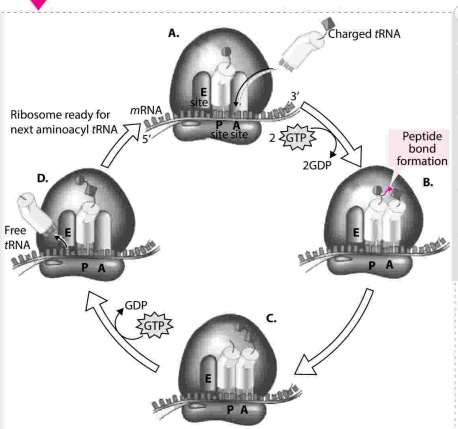
2 Initiation

- Eukaryotic cells have atleast nine initiation factors, *i.e.*, **eIF2, eIF2B, eIF3, eIF4A, eIF4B, eIF4E, eIF4G, eIF5** and **eIF6**.
- The first step is the formation of a **pre-initiation complex** consisting of the 40S small ribosomal subunit, Met-*t*RNA$_i^{Met}$, eIF2 and GTP;
- The pre-initiation complex now binds to the 5′end of the eukaryotic *m*RNA, a step that requires **eIF4F** complex (eIF4A, eIF4E, eIF4G, also called **cap binding complex**) and **eIF3**. Thus, this complex intact both the 5′and 3′ends of the *m*RNA.
- The eIF4A is a RNA helicase that unwinds any secondary structure of *m*RNA, preparing it for translation.
- The complex now moves along the *m*RNA in a 5′to 3′direction until it locates the AUG initiation codon (*i.e.*, scanning of *m*RNA).
- Once the complex is positioned over the initiation codon, the 60S large ribosomal subunit binds to form an **80S initiation complex**, a step that requires the hydrolysis of GTP and leads to the release of several initiation factors.



3 Elongation

- Elongation requires three factors, *i.e.*, **EF – Tu, EF – Ts** and **EF – G** and enzyme **peptidyl transferase**.
- The *f*Met-*t*RNA$_f^{Met}$ occupies the P site and another aminoacyl *t*RNA complex (aminoacyl *t*RNA – EF – Tu – GTP) reach at A site depending upon the anticodon present on *m*RNA. EF – Ts and GTP are required for the regeneration of **EF – Tu – GTP complex**.
- First peptide linkage is now established between –COOH group of amino acids at P site and –NH_2 group of amino acid at A site catalysed by the ezyme peptidyl transferase.
- This produces a dipeptidyl – *t*RNA in the A site and now uncharged *t*RNA$_f^{Met}$ remains bound to the P site. With the help of EF – G (translocase) dipeptidyl - *t*RNA moves from A site to P site. The ribosome moves one codon toward the 3′ end of *m*RNA (called translocation). Free *t*RNA slips to E site and from there to outside in the cytoplasm.
- New codon exposed at A site attract new aminoacyl *t*RNA complex and thus peptide chain elongates.



3 Elongation

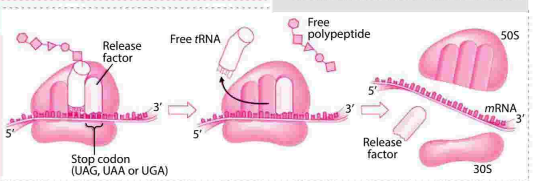
- The elongation stage of translation in eukaryotes is quite similar to the prokaryotes.
- It requires three elongation factors, **eEF1α**, **eEF1βγ** and **eEF2** as counterparts of prokaryotic EF – Tu, EF – Ts and EF – G respectively.
- The GTP form of EF1α delivers aminoacyl *t*RNA to the A site of the ribosome and EF1βγ catalyses the exchange of GTP for bound GDP. eEF2 mediates GTP driven translocation similar to prokaryotic EF – G.
- As eukaryotic ribosome do not have E site, uncharged *t*RNAs are expelled directly from the P site.
- The elongated peptide chain or polypeptide lies in the groove of the larger subunit of ribosome.

4 Termination

- Termination in eukaryotes is similar to that in prokaryotes.
- In eukaryotes, a single factor **eRF1** recognises all three termination codons and with the help of eRF3, ribosomal subunits are released.
- eRF3 prevents the reassociation of ribosomal subunits in the absence of an initiation complex.

4 Termination

- Termination occurs when a **non sense** or **stop codon** (UAA, UAG, UGA) reaches A site.
- Stop codons are recognised by 2 release factors **RF1** and **RF2**. A third factor **RF3** mediates interaction between RF1 or RF2 with the ribosome.
- RF1 is specific to UAG and UAA.
- RF2 is specific to UAA and UGA.
- RFs hydrolyse the terminal peptidyl-*t*RNA bond, release polypeptide and last *t*RNA from the P site and dissociates two subunits of ribosomes to start new cycle of translation.



CONCEPT MAP

HUMAN EVOLUTION

The process of evolution involves a series of natural changes that cause species to arise, adapt to the environment and become extinct. Humans too have originated through the process of biological evolution. The study of human evolution is called Paleoanthropology. Most of the scientists currently recognise 15-20 different species of early humans, of which major landmark species are discussed below.

First ape man

Australopithecus africanus

Period : 5 million years ago (Pliocene)
Location : Pliocene rocks near Tuang in Africa
Brain size : 500 cc.
Adaptations : Bipedal locomotion, omnivorous but mostly vegetarian feeding on fruits, vegetables, nuts, seeds and eggs. Erect posture but climbed trees too.
Characteristics : Fully human shaped jaw and human like pelvis. Brow ridges projecting over eyes. Absence of chin. Lumbar curve in vertebral column.

Australopithecus afarensis

Period : 3.9-2.9 million years ago (Pliocene)
Location : Ethiopia, Tanzania
Brain size : 375-500cc (male and female size different)
Adaptations : Bipedal locomotion, walked upright and survived during dramatic climate fluctuations.
Characteristics : Looked and acted like ape. From waist down resemble humans (having pelvis and tibia/femur). Lived both on ground and on trees. Presence of lunate sulcus makes their occipital lobe smaller, suggesting greater reasoning skills and more control of motor functions.

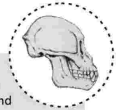
GAP

Ramapithecus

Period : 14-15 million years ago (from late Miocene to Pliocene)
Location : Pliocene rocks of Shivalik Hills of India.
Brain size : Unknown
Adaptations : Walk erect on its hind feet on ground and lived on tree tops.
Characterstics : Small canines and large molars like humans. Ate hard nuts and seeds.

Common ancestor of man and apes

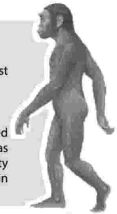
Dryopithecus



Period : 20-25 million years ago (Miocene)
Location : Miocene rocks of Africa and Europe
Brain size : Large (size not known)
Adaptations : Arboreal and ate soft fruits and leaves, semi-erect posture.
Characteristics : Arms and legs of same length, feet with heels, without brow ridges, knuckle walker.

Homo habilis

Period : 1.5-2 million years ago (Pleistocene)
Location : Pleistocene rocks to olduvai Gorge in East Africa.
Brain size : 700 cc, with an expansion of frontal lobe.
Adaptations : Bipedal locomotion, omnivorous
Characteristics : 1.2- 1.5 metres tall, had a nose and elevated forehead. Thumbs broader, teeth like modern man. Tool maker (as found with heaps of tools made from chipped stones). Community life, lived in caves. Nurtured young ones. Successful due to change in climate.



Able or skillful man

Homo erectus

(Erect man)

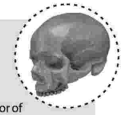
Period : 1.8 -1.7 million years ago (Middle Pleistocene)
Location : Africa, Europe, Asia
Brain size : 800-1300 cc.
Adaptations : Erect posture, omnivorous and first to eat animal meat and take care of old.
Characteristics : 1.5-1.8 metres tall. Skull flatter and cranium dome shaped to accommodate large brain. Protruding jaws, projecting brow ridges. Small canines and large molar teeth. Increase in intellect, memory and speech usage. Ability to run on two legs and less body hair which allowed sweating. Males were larger than females. Made elaborate tools of stones and bones, hunted for meat. Use of fire probably for cooking and protection. Group living forming hunts-gatherer society.

Longest lived species

Direct ancestor of living modern man

Homo sapiens fossilis

(Cro-Magnon man)



Period : 50,000-10,000 years ago (Holocene)
Location : Cro-Magnon rocks in France.
Brain size : 1650 cc
Adaptations : Walk and run faster, omnivorous, direct ancestor of living modern man.
Characteristics : Well built body and about 1.8m tall. Face orthognathous with an elevated nose, broad and arched forehead and moderate brow ridges. Strong jaws with teeth close together and a well developed chin. Lived in families in caves. Made excellent tools as spears, bows and arrows as well as ornaments from stones, bones and elephant tusks. Had art and culture, obvious from carvings and paintings in caves. Became extinct about 10,000-11,000 yrs ago.

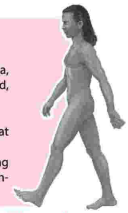
Homo sapiens neanderthalensis

(Neanderthal man)

Period : 400,000-300,000 years ago. (Late Pleistocene)
Location : Neander valley in Germany.
Brain size : 1,300-1,600cc
Adaptations : Walked upright with bipedal movement, cannibals.
Characteristics : Slightly prognathous face, low brows, receding jaws and high domed heads. Diet include significant amount of meat supplemented with vegetation. Skilled hunters with simple tools as heavy spears or knives to kill prey. First to use skin hides as clothing so as to protect from harsh environment. Legendary cave dwellers, illuminated and heated them with fire. First hominids to bury dead and may had religion.

Homo sapiens sapiens

Period : 25,000 years ago (Holocene)
Location : First appeared around Caspean and Mediterranean sea, from where it migrated and changed into present day Caucasoid, Mongloid and Negroid races.
Brain size : Approx 1450 cc
Adaptations : Reduction in cranial capacity and cultural evolution rather than that of anatomy.
Characteristics : Slightly raised skull cap, thinning of skull bones, forehead rising sharpely. Four curves in vertebral column. Prominent chin, thin skeleton and non-existent brow ridges. Reduction in tooth and facial bone size.



Living modern man

Sub-species of *Homo erectus*

Pithecanthropus erectus

(Java ape man)

Period : Pleistocene
Location : Pleistocene rocks in central Java, an island of Indonesia.
Brain size : 800-1000 cc
Adaptations : First prehistoric man with long legs and erect body, but slightly bent when moving, omnivorous and cannibal.
Characteristics : 1.65-1.75m tall and weighing about 70 kg. Skull cap thick and heavy but flattened in front. Forehead low and receding but brow ridges high (as in apes). Inconspicuous chin and broader nose, lower jaw large and heavy. Canines of lower jaw larger and lips thick and protruding. Use of fire for hunting, defence and cooking.

Homo erectus pekinensis

(Peking man)

Period : 1.8 million -300,000 years ago (Pleistocene)
Location : Rocks of limestone caves of Choukoutien, near Peking (China).
Brain size : 850 -1100 cc (large cranial capacity)
Adaptations : Omnivorous and cannibal
Characteristics : Similar in structure to Java man, except that Peking man was slightly shorter (1.55-1.60m tall), lighter and weaker. Used to live in caves in small tribes. Tools used were more sophisticated.

Homo erectus heidelbergensis

(Heidelberg man)

Period : 500,000 years ago (Middle Pleistocene)
Location : Near Heidelberg, Germany.
Brain size : 1100-1400 cc
Adaptations : Intermediate between erectus and Neanderthal man, first to venture into cold climate.
Characteristics : Human like teeth and ape like massive jaw. Receding forehead and lack of chin. Use of tools and fire. First species to build substantial shelters and showed planning symbolic behaviour. Gave rise to both Neanderthals and modern humans.

CONCEPT MAP

MALARIA : CAUSE, SYMPTOMS AND TREATMENT

Malaria is an acute febrile illness that results in intermittent fevers; and is caused by a parasite of Genus *Plasmodium* belonging to a protozoan Phylum, Apicomplexa. The parasite shows an alternation of generation accompanied by an alternation of host (**digenetic**). Asexual cycle (schizogonic cycle) occurs inside the red blood cells of the vertebrate host (human) and sexual cycle (sporogonic cycle) occurs in an invertebrate host *(Anopheles* mosquito). Malarial parasite is transmitted to human through the bite of infected female *Anopheles* mosquito during its blood-meal. Distinct species of *Plasmodium* are *Plasmodium malariae* (causes quartan malaria), *Plasmodium vivax* (causes benign tertian malaria), *Plasmodium falciparum* (causes malignant tertian malaria) and *Plasmodium ovale* (causes mild tertian malaria). **Laveran** (1880) discovered the malarial parasite, *Plasmodium*. **Sir Ronald Ross** (1897) observed that malarial parasite is transmitted by the bite of a female , *Anopheles* mosquito.

LIFE CYCLE OF *PLASMODIUM*

The life cycle of *Plasmodium* requires two hosts, mosquito and human.

MOSQUITO
(Definitive or primary host)

HUMAN
(Intermediate or secondary host)

1 **Infected hepatocyte**
Sporozoites travels in the bloodstream and reach liver cells (hepatocytes). After penetrating a hepatic cell each sporozoite becomes a **cryptozoite**.

2 **Hepatic schizont**
Cryptozoite grows for a number of days and becomes spherical and non-pigmented **schizont** which divides by schizogony to form a large number of uninucleate cells, **cryptomerozoites**.

3 They enter fresh liver cells to become **metacryptozoites** which again undergo schizogony to form metacryptomerozoites and this is referred to as **exoerythrocytic cycle**.

4 **Metacryptomerozoites in bloodstream:** Further the liver cells rupture and release thousands of metacryptomerozoite-stage parasites into bloodstream that infect red blood cells.

5 Metacryptomerozoite becomes rounded to form young **trophozoite**.

6 Trophozoite grows and a central vacuole is developed pushing the nucleus to periphery. This stage is referred to as **signet ring stage**. Trophozoites acquire brownish-black **haemozoin** granules. These granules are produced by the decomposition of haemoglobin derived from the cytoplasm of the erythrocytes.

7 Signet ring trophozoite form an active amoeboid trophozoite. It sends pseudopodial processes into cytoplasm of RBC. At this time eosinophilic granules called **Schuffner's granules** appear in the cytoplasm of the host corpuscles.

8 Amoeboid trophozoite after feeding, becomes rounded, grows in size and becomes **schizont**. Its cytoplasm with one nucleus forms merozoites.

9 **Amplification of Infection**
Schizont ruptures to release merozoites which invade fresh corpuscles to repeat erythrocytic cycle and amplify the infection.

10 **Gametocytes**
When impulse to multiply asexually by schizogony is exhausted, the merozoites in RBC increase in size to become gametocytes. Microgametocyte (♂) is smaller and contains a large diffused nucleus. Megagametocyte (♀)is larger and has a small, compact peripheral nucleus.

Magnified view

Erythrocyte

Trophozoite

SCHIZOGONIC CYCLE

1 Another mosquito bites infected human and ingests gametocytes. The male and female gametocytes remain undigested in the mosquito's gut. The gametocytes come out of the RBCs into the lumen of the stomach of mosquito. The male gametocytes divide and form long motile, whip-like microgametes. The female gametocytes do not divide and mature to become macrogametes.

Mosquito ingests gametocytes with blood-meal

♀ ♂

2 Fusion

Microgamete

3 Diploid zygote

4 **Ookinete**
Zygote further becomes worm like, motile and is known as **ookinete**.

5 Ookinete penetrates through the wall of midgut (stomach) and settles down just under the thin membrane that separates midgut from haemocoel.

SPOROGONIC CYCLE

6 **Oocyst**
Ookinetes become immobile and begin to encyst resulting in the formation of oocyst. Ookinetes form large number of sporozoites through sporogony.

7 **Oocyst** ruptures to release sporozoites.

8 These sporozoites are liberated into the haemocoel of the mosquito and finally to the salivary glands. The mosquito becomes infective.

9 Infected female *Anopheles* mosquito bites human for a blood-meal. During biting mosquito's proboscis pierces the skin and injects sporozoites *via* saliva into the blood stream.

Salivary gland

SYMPTOMS

Common symptoms include chills, fever, malaise, muscular pain, severe headache, sweating, nausea. In severe cases haemoglobin in the urine, cerebral malaria (coma) and retinal damage, etc. occur.

DIAGNOSIS

Diagnosis of malaria is usually done by examination of thin and thick blood smears.

TREATMENT

Various antimalarial drugs are used to cure malaria such as **chloroquine, camoquin, sulfadoxine**, etc. Antimalarial vaccine known as **RTS, S** is the world's first malaria vaccine to obtain a positive scientific opinion.

PROPHYLAXIS

Protection against mosquito bite can be achieved by using mosquito repellents and insecticide treated mosquito nets. Destruction of mosquitoes by spraying D.D.T or gammexane. Adopting antilarval measures by eliminating breeding places and using larvicides (Oil, fenthion, thermiphos, etc.)

RECURRENT MALARIA

Relapse is a re-attack of malaria because of infection by the malarial parasites that were surviving in the liver cells (hypnozoites). Among the malarial parasite species that infect humans, *P. vivax P. falciparum* and *P. malariae* can develop dormant liver stages that can reactivate after symptomless intervals of upto 2 to 4 years.

Recrudescence is a re-attack of malaria because of the surviving malaria parasites in red blood cells. It occurs in all four species of *Plasmodium*. It is the reappearance of infection from persistent blood stages of malarial parasites (drug resistance).